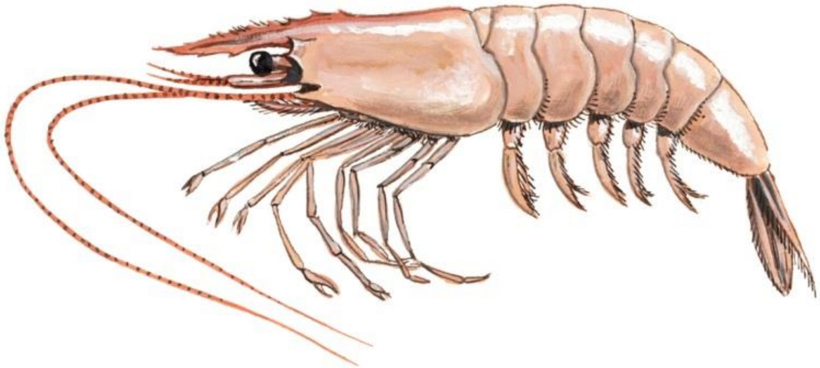
Whiteleg Shrimp

Litopenaeus vannamei



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United States

Outdoor Ponds

Report ID 27834

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About Seafood Watch®

The Monterey Bay Aquarium Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the North American marketplace. Seafood Watch defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. The program's mission is to engage and empower consumers and businesses to purchase environmentally responsible seafood fished or farmed in ways that minimize their impact on the environment or are in a credible improvement project with the same goal.

Each sustainability recommendation is supported by a seafood report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's sustainability criteria to arrive at a recommendation of "Best Choice," "Good Alternative," or "Avoid." In producing the seafood reports, Seafood Watch utilizes research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch research analysts also communicate with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying seafood reports will be updated to reflect these changes. Both the detailed evaluation methodology and the scientific reports, are available on seafoodwatch.org.

For more information about Seafood Watch and seafood reports, please contact the Seafood Watch program at Monterey Bay Aquarium by calling 1-877-229-9990 or visit online at seafoodwatch.org.

Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[1] or farmed, that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

The following **guiding principles** illustrate the qualities that aquaculture must possess to be considered sustainable by the Seafood Watch program:

Seafood Watch will:

- Support data transparency and therefore aquaculture producers or industries that make information and data on production practices and their impacts available to relevant stakeholders.
- Promote aquaculture production that minimizes or avoids the discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges beyond the immediate vicinity of the farm.
- Promote aquaculture production at locations, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats without unreasonably penalizing historic habitat damage.
- Promote aquaculture production that by design, management or regulation avoids the use and discharge of chemicals toxic to aquatic life, and/or effectively controls the frequency, risk of environmental impact and risk to human health of their use.
- Within the typically limited data availability, use understandable quantitative and relative indicators to recognize the global impacts of feed production and the efficiency of conversion of feed ingredients to farmed seafood.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild fish or shellfish populations through competition, habitat damage, genetic introgression, hybridization, spawning disruption, changes in trophic structure or other impacts associated with the escape of farmed fish or other unintentionally introduced species.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.
- Promote the use of eggs, larvae, or juvenile fish produced in hatcheries using domesticated broodstocks thereby avoiding the need for wild capture.
- Recognize that energy use varies greatly among different production systems and can be a major impact category for some aquaculture operations, and also recognize that improving

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[1] "Fish" is used throughout this document to refer to finfish, shellfish and other invertebrates.

practices for some criteria may lead to more energy intensive production systems (e.g., promoting more energy intensive closed recirculation systems).

Once a score and rank has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ranks and the overall recommendation are color-coded to correspond to the categories on the Seafood Watch pocket guide:

Best Choices/Green: Buy first, they're well managed and caught or farmed in ways that cause little harm to habitats or other wildlife.

Good Alternatives/Yellow: Buy, but be aware there are concerns with how they’re caught or farmed.

Avoid/Red: Don't buy, they're overfished or caught or farmed in ways that harm other marine life or the environment.

Final Seafood Recommendation

Whiteleg Shrimp (*Litopenaeus vannamei*)
United States
Outdoor Ponds

Criterion	Score (0-10)	Rank	Critical?
C1 Data	8.06	GREEN	
C2 Effluent	8.00	GREEN	NO
C3 Habitat	9.17	GREEN	NO
C4 Chemicals	6.00	YELLOW	NO
C5 Feed	3.87	YELLOW	NO
C6 Escapes	5.00	YELLOW	NO
C7 Disease	8.00	GREEN	NO
C8 Source	10.00	GREEN	
C9X Wildlife mortalities	–2.00	GREEN	NO
C10X Introduced species escape	0.00	GREEN	
Total	**56.09**		
Final score	**7.01**		

OVERALL RANKING

Final Score	7.01
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO
FINAL RANK	**BEST CHOICE**

Scoring note – scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact.

Summary
Whiteleg shrimp farmed in the United States receives a final numerical score of 7.01 and, with no Red criteria, the overall recommendation is “Green.”

Executive Summary

This assessment was originally published in August 2014 and reviewed for any significant changes in July 2022. No changes were made to the body of the report. Please see Appendix 4 for details of the review. Whiteleg shrimp produced in the U.S. using Recirculating Aquaculture Systems (less than 5% of the industry) fall out of the scope of this assessment, but are included in the Seafood Watch "Global – Recirculating Aquaculture Systems (indoor, tank-based) – All species" assessment[2].

The whiteleg shrimp (*Litopenaeus vannamei*, formerly *Penaeus vannamei*), also called Pacific white shrimp, is an eastern Pacific Ocean shrimp commonly caught or farmed for food. The United States imports 1.2 billion pounds (lb) of shrimp (both wild captured and aquacultured) each year, and currently produces 4 million lb per year through aquaculture. Aquaculture production of *L. vannamei* in the United States is quite minor compared to global production values.

Most commercial shrimp aquaculture production in the U.S. is located in Texas, which has seven commercial farms. There is less production through fewer shrimp farms per state in Alabama (3), Florida (3), Hawaii (2), Nevada (1), Michigan (1), Indiana (1), Iowa (1), Maryland (1), Massachusetts (1), and the U.S. territory of Guam (2).

U.S. farms vary in size and production volume, with a combined total of 4 million lb produced in 2013. The 7 farms in Texas produced 2.4 million lb in 2013, down from 15 Texas farms producing 9 million lb in 2003. The total production from the other U.S. farms combined is estimated at 1 to 2 million lb a year. The greatest combined production by U.S. shrimp farms occurred in 2003 with a total of 13 million lb.

Overall, data availability for the U.S. shrimp aquaculture industry is good, but the small size of the industry limits the national reporting on production volumes, exports/imports, and more detailed production factors. Further, the small industry size has led to scarcity on production data of whiteleg shrimp in the U.S. But, there are numerous research papers and reports published every year concerning the U.S. shrimp farming industry on a variety of topics such as nutrition (diets using less fishmeal), diseases, genetic selection, and improved production techniques and technologies. There are a number of prominent trade associations and state aquaculture associations that produce newsletters and there are scientific journals and industry publications that publish shrimp farming information. Also, the author of this report has extensive personal experience in the U.S. shrimp farming industry. The score for Criterion 1—Data is 8.06 out of 10.

U.S. shrimp aquaculture principally utilizes pond production systems with infrequent water exchange, mitigating the downstream effluent impacts. Data show no evidence of adverse effluent impacts from U.S. shrimp farms today. In addition, best management practices coupled

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[2] https://www.seafoodwatch.org/recommendation/shrimp/whiteleg-shrimp-29994?species=156

with strong federal and state regulations and enforcement further reduce the risk of environmental impacts from effluents. Regulations on the coast are that any discharge must be equal to or of better quality than the receiving waters. Each farm's requirements for effluent are individually set specifically for the site where it is located. The effluent score in this assessment reflects the regulation and oversight on discharge releases and the use of constructed wetland filtration systems or settling facilities to limit the release of solids, organic matter, and nutrients. The score for Criterion 2—Effluent is 8 out of 10.

The majority of U.S. shrimp farms were converted from terrestrial crop farms, and no sensitive or high-value habitats are affected by U.S. shrimp aquaculture. Minimal habitat impacts have occurred, but no overall loss of habitat functionality has been experienced. Shrimp farms in the U.S. are heavily regulated by both state and federal agencies, and robust federal and regional legislation and enforcement prohibits significant habitat impacts from occurring. Thus, the Criterion 3—Habitat score is 9.17 out of 10.

Disease outbreaks are uncommon in U.S. shrimp aquaculture, so the need for chemical use is demonstrably low. "High Health" or specific-pathogen-free (SPF) shrimp sources have helped control disease, especially viruses, and limit the need for chemical or antibiotic treatment for bacterial infections. The most common chemical used is agricultural lime, which is often used to disinfect pond bottoms after harvest. Although select instances of chemical use have historically occurred, best management practices currently mitigate the risk of disease outbreaks and minimize the need for chemical use. The final numerical score for Criterion 4—Chemical Use is 6 out of 10.

Commercial U.S. shrimp aquaculture achieves a feed conversion ratio (FCR) of 1.80 by utilizing feeds containing 25% fishmeal and 6% fish oil. The Fish In:Fish Out (FIFO) ratio is 2.16 and is relatively high compared to shrimp culture outside the U.S. The principal source fishery for fishmeal and fish oil is Gulf menhaden, which has a Seafood Watch ranking of Yellow. U.S. shrimp aquaculture results in a significant net loss of protein (–63.91%) and a total feed footprint of 14.74 hectares of land and ocean area, which are required to produce the feed ingredients needed to grow one ton of shrimp. The final Criterion 5—Feed score is 3.87.

The production system that represents the greatest risk of farmed shrimp escape is coastal outdoor ponds. Raised pond dikes, multiple screens at discharge points, and other best management practices mitigate the risk of escape; however, this risk is still considered low to moderate. Although escaped shrimp can interact with wild populations, hybridization and the subsequent deleterious genetic impacts are highly unlikely. The score for Criterion 6—Escapes is 5 out of 10.

Although several shrimp diseases are problematic in the global industry, the United States has historically had relatively few instances of disease outbreaks and mortality. Some examples of outbreaks are known, but research and development of biosecurity and best management practices have mitigated both the risk of outbreak as well as the transmission to wild populations. To date, there is no evidence that diseases from shrimp farms have adversely affected wild populations. The score for Criterion 7—Disease is 8 out of 10.

Juvenile shrimp for stocking are sourced exclusively from domestic hatcheries in the U.S. (KAAPA Farms in Bayview, Texas or Shrimp Improvement Systems (SIS) in Islamorada, Florida). Therefore, farmed stocks are completely independent of the wild populations and the score for Criterion 8—Source of Stock is 10 out of 10.

Aquaculture operations attract or interact with predators or other wildlife, so wildlife and predator mortality can be a concern. But, no threatened or endangered species are affected, and effective management and prevention measures in the U.S. shrimp aquaculture industry limit mortalities to exceptional cases, with no population-level impacts shown to occur. The numerical score for Exceptional Criterion 9X is –2 out of –10.

The biosecurity of both the source and destination facilities in U.S. shrimp farming is shown to be high. Thus, the concern regarding the escape of intentionally introduced species (other than the farmed shrimp) is null. The final score for Exceptional Criterion 10X is 0 out of –10.

Overall, whiteleg shrimp production in the United States is shown to result in only minor environmental impacts. Chemicals, feed, and escapes were the lowest-scoring criteria (all scored in the yellow range) and these lower scores represent the elevated “potential” or risk of environmental impacts—not any actual historical environmental impacts.

The final numerical score of 7.01 represents an overall ranking of Green and is the result of a mix of Yellow and Green scores for the criteria, with no Red or critical scores.

Table of Contents

Introduction

An interim update of this assessment was conducted in July 2022. This section was updated with new information. The interim update can be found in Appendix 4 at the end of this document.

Scope of the analysis and ensuing recommendation

Species. Whiteleg shrimp, *Litopenaeus vannamei*

Geographic coverage. United States

Production Methods. Outdoor ponds

Species Overview

Biology: Whiteleg shrimp (*Litopenaeus vannamei*)

The whiteleg shrimp (*Litopenaeus vannamei*, formerly *Penaeus vannamei*), is a marine crustacean belonging to the order Decapoda and the family Penaeidae. The body is translucent and often has a bluish-green hue due to the presence of pigmented chromatophores (molecules evolved to collect/reflect light). *Litopenaeus vannamei* (Figure 1) can reach 230 mm (9 in) in length and is native to warm, eastern Pacific waters ranging from Sonora, Mexico to Tumbes in northern Peru (Figure 2) (Farfante and Kensley 1997). Its preferred habitat ranges from muddy bottoms of the shoreline to depths of 72 m (235 ft) (Dore and Frimodt 1987). The anatomy and life history of *L. vannamei* are similar to other members of the family Penaeidae.

Figure 1. *Litopenaeus vannamei* (note characteristic red antennae)

Weight at first maturity ranges from 20 g for males to 28 g for females, and is usually obtained between 6 and 7 months of age. Female *L. vannamei*, weighing 30 to 45 g, spawn 100,000 to 250,000 eggs that are approximately 0.22 mm in diameter. Hatching occurs approximately 12 to 16 hours after fertilization, depending upon temperature.

The growth and survival of *L. vannamei* postlarvae are strongly dependent on temperature and salinity. Survival and growth coincide best at around 28–30 ˚C and 33 to 40 ppt (Ponce-Palafox et al. 1997). Survival of juveniles is severely compromised at low salinities and high temperatures (Ponce-Palafox et al. 1997).

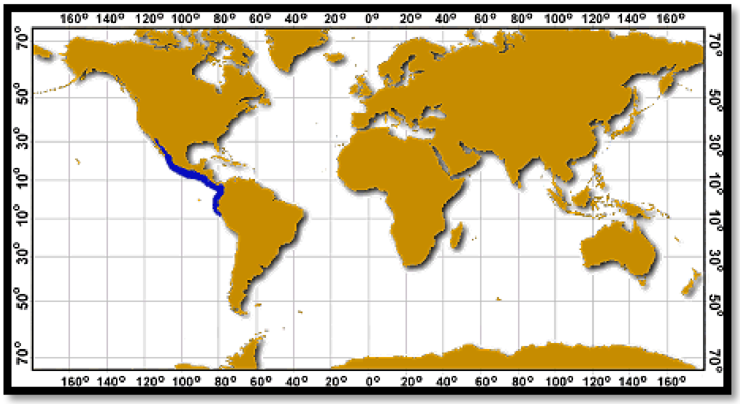


Figure 2. The native geographic range of *L. vannamei.* www.fao.org—from Holthuis 1980

World Trends

The demand for protein by an increasing world population combines with decreasing yields from capture fisheries to drive the rapid growth of aquaculture. Global aquaculture now accounts for 40% of overall seafood production (50% for finfish) and supplies 60% of the world shrimp demand (FAO 2010 and 2013). Annual growth of world shrimp farming over the last decade has been estimated at 10% (Valderrama and Anderson 2011). This rapid expansion has resulted in some significant environmental impacts: traditional pond culture discharges nutrients, organic waste, and sometimes disease vectors that damage coastal environments (Cowey and Cho 1991). Uncontrolled growth already has imposed heavy losses on the industry and raised justifiable criticism that threatens further development (Naylor et al. 2000).

The global capture fishery for this species has declined since 1993. The wild catch has dropped from 14,000 tons in 1993 to 1,100 tons in 1999. A production graph can be seen at FishSource, 2013a.

A number of references have given detailed accounts of the history of shrimp farming. World history references are: Ling 1977, Scura 1987, Tseng 1987, Yuan et al. 2006, and Stickney and Treece 2012. U.S. shrimp farming history references are: Treece 1993, Cheshire 2005, Rosenberry 2007, and Stickney and Treece 2012.

U.S. Shrimp Culture

Despite the world trend of growth, U.S. shrimp aquaculture has shown an annual decline since production peaked in 2003 at 13 million pounds (lb). The U.S. thus remains a net shrimp importer, with annual shrimp imports of 1.2 billion lb worth $4.5 billion (USDA 2013)(NOAA 2011)(NOAA 2012).

Commercial Shrimp Farms in the U.S. (2014)

1. Texas Farms: KAAPA Farms, San Tung, Bowers, Bowers Valley, Natural Shrimp International, Michael Shrimp Farm, Global Blue Technologies. Seven farms totaling 853 acres. Outdoor ponds located in inland and coastal regions, plus two indoor facilities, one inland and one on the coast.
2. Florida: Woods Fisheries. 56 acres. Outdoor ponds located 5 miles inland, and Florida Organic Aquaculture and American Mariculture, Inc., which are indoor facilities located inland or on an island, but considered inland. Florida Organic Aquaculture leases land approximately 10 acres for their farm and American Mariculture, Inc. has 8.5 acres.
3. Alabama: Green Prairie Aquafarm and several others. About 100 acres total. Outdoor ponds, located inland.
4. Michigan, Iowa, Massachusetts, Nevada, Indiana, Maryland: all indoor facilities.
5. Hawaii: Outdoor ponds and one indoor facility. There are several shrimp broodstock production companies that sell shrimp worldwide.
6. Guam and Saipan: Outdoor ponds.

The largest and highest production volume farm in the U.S. is located in Collegeport, Texas (Bowers Shrimp and Catfish). It holds and reuses its effluent, but does periodically discharge into coastal waters. Another operation, located on the coast in Port Isabel, Texas, is a zero-discharge shrimp raceway operation. It received the first zero discharge permit issued by the Texas Commission on Environmental Quality several years ago, and is building a large, commercial indoor RAS facility on the coast near Rockport, Texas on Port Bay. With respect to inland farms in Texas, there is one in San Antonio that utilizes low salinity water in raceways under a greenhouse, and another being built in Lasara (near Raymondville) that is an outdoor pond-based farm with infrequent or periodic discharge of low salinity groundwater into a recreational fishing lake or fee fishing lake. The farms in Alabama and Florida are similar to this and utilize outdoor pond-based operations with infrequent or periodic discharge of low salinity groundwater (2 to 5 ppt). The Florida regulatory agency in charge of groundwater requires 7 test wells to be sampled yearly by Woods Fisheries shrimp farm outside Port St. Joe, for potential salination of drinking water (pers. comm., Mark Godwin, General Manager of Woods Fisheries farm outside St. Joe, FL August 2013). Florida Organic Aquaculture utilizes 32 ppt salt water from a well 2,600 feet deep. They are located inland at Fellsmere, Florida. They plan to utilize *Salicornia* beds and grow *Salicornia* (a succulent saltwater plant used in the health food industry and as animal feed once it is cut and dried), fed by their effluent. Bob Rosenberry (Shrimp News International, June, 2014), gave details from Robin Pearl, president of American Mariculture, Inc., which operates an intensive shrimp farm in St. James City on Florida's Gulf Coast. Their shrimp are raised without chemicals, antibiotics, or preservatives, and marketed under the Sun Shrimp brand. American Mariculture's farm is located on 17-mile-long Pine Island, the largest island off Florida's west coast (Figures 3 and 4).

Figure 3: American Mariculture, Inc. on Pine Island, Florida.

Figure 4: Florida map showing location of major commercial shrimp aquaculture facilities (modified from Rosenberry 2014).

The company grows whiteleg shrimp (*Litopenaeus vannamei*) at its biosecure farm that consists of 8.5 acres of rectangular tanks, all under greenhouses. For more details see Rosenberry 2014.

Research on shrimp culture was conducted in the U.S. starting in the 1960s, with true commercial aquaculture operations being established in the 1980s to early 1990s along the Gulf Coast, with Texas leading the effort. Texas has consistently produced 70% to 80% of the total farm-raised shrimp in the U.S. There were seven commercial farms with about 900 acres of production in the state in 2012 producing about 2.9 million lb of heads-on shrimp. Grow-out takes 4 to 6 months for the shrimp to reach market size, and the farm-gate price in 2013 is about $2.50 per lb with head-on. Two operations in Texas dominate production, and both are large coastal farms. Alabama has one large farm and several smaller operations, and they are all inland farms utilizing brackish groundwater. Florida has three inland producers (two indoor facilities and one producing in outdoor ponds). All the Alabama farms are located inland, away from coastal habitats.

Shrimp farm production in the U.S. peaked in 2003 with 13 million lb produced (Figure 5). Of that, 9 million lb were produced in Texas. Production declined steadily until 2010, when it seemed to have stabilized to 3 to 4 million lb per year. The 2011 production was 4 million lb and 2012 was the same, with Texas still producing the majority of the volume. U.S. shrimp aquaculture is quite small compared to imports (Table 1). U.S. farmed shrimp production by state in 2009 can be seen in Table 2.

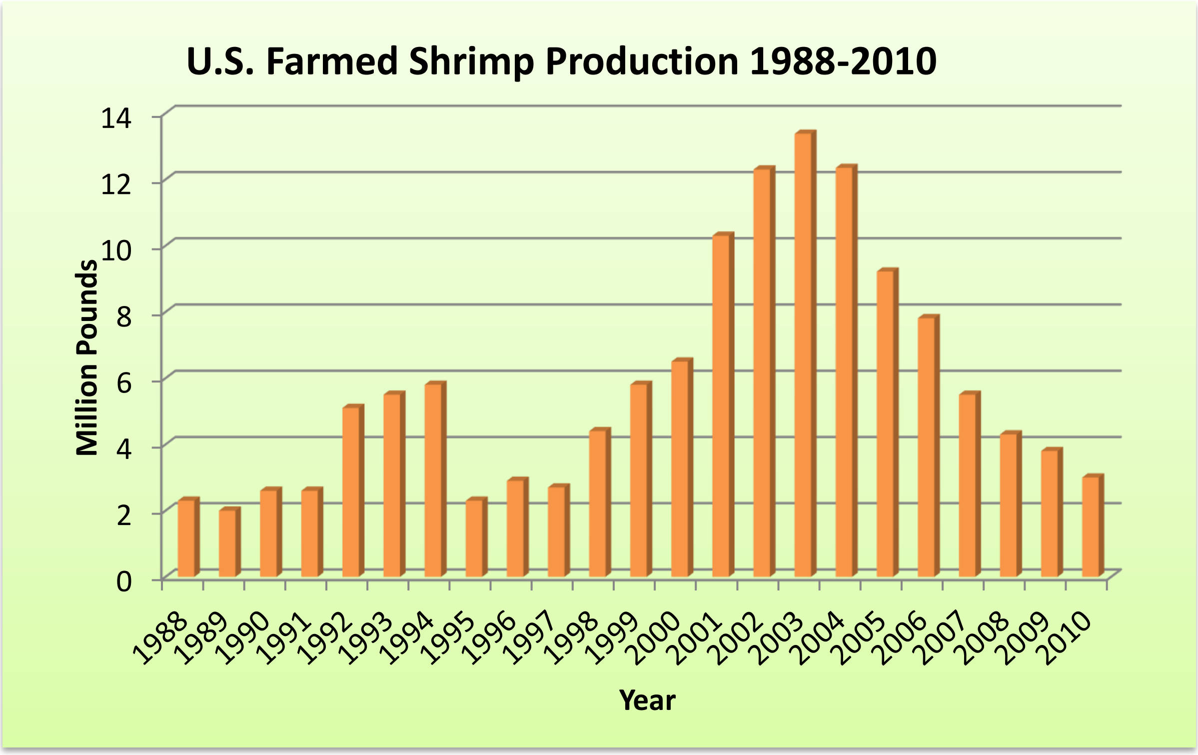
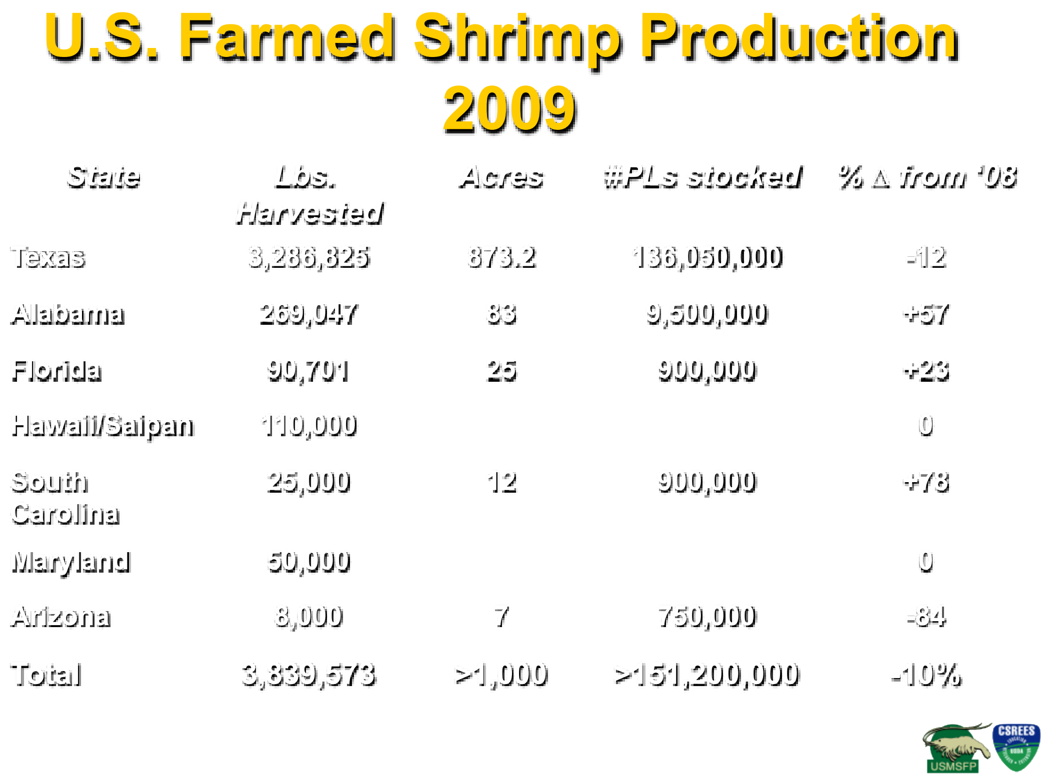


Figure 5: U.S. farmed shrimp production 1988–2010. Source: USDA U.S. Marine Shrimp Farming Program.

Table 1. U.S. Shrimp Aquaculture Production (*L. vannamei)* and Yearly Shrimp Imports in U.S. (all species). Source: USDA U.S. Marine Shrimp Farming Program and USDA-ERS

Year	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
United States production (billion lb)	0.0041	0.0038	0.003	0.004	0.004	0.004
U.S. shrimp imports (billion lb)	1.243	1.209	1.231	1.27	1.2	1.2
% contribution of U.S. production to consumption	0.003	0.003	0.002	0.003	0.003	0.003

Table 2. U.S. farmed shrimp production detail 2009. Source: USDA U.S. Marine Shrimp Farming Program



U.S. Farmed Shrimp Production 2009

State	Lbs. Harvested	Acres	#PLs stocked	% ∆ from '08
Texas	3,286,825	873.2	136,050,000	-12
Alabama	269,047	83	9,500,000	+57
Florida	90,701	25	900,000	+23
Hawaii/Saipan	110,000			0
South Carolina	25,000	12	900,000	+78
Maryland	50,000			0
Arizona	8,000	7	750,000	-84
Total	3,839,573	>1,000	>151,200,000	-10%

Common and market names

Whiteleg shrimp, more commonly called Pacific white shrimp, is also sometimes referred to as the Mexican white shrimp.

Most Common Product forms

Whole chilled on ice, whole frozen (IQF), fresh or frozen tails with shell on ("green headless"), peeled and deveined tails, peeled and breaded IQF frozen tails. A more detailed list of product forms with photos can be found in Cascorbi 2004.

Analysis

Scoring guide

- With the exclusion of the exceptional criteria (9X and 10X), all scores result in a zero to ten final score for the criterion and the overall final rank. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the two exceptional criteria result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Criteria that the following scores relate to are available on the Seafood Watch web site.
- The full data values and scoring calculations are available in Annex 2.

Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

- *Impact: data is readily available on the industry in the U.S., which allows us to further understand the impacts of aquaculture production. It does enable informed choices for seafood purchasers, and enables businesses to be held accountable for their impacts by stringent environmental regulations set in place in the U.S.*
- *Sustainability unit: the ability to make a robust sustainability assessment*
- *Principle: robust and up-to-date information on production practices and their impacts is available to relevant stakeholders.*

Criterion 1: Data quality and availability

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	Yes	10	10
Effluent	Yes	7.5	7.5
Locations/habitats	Yes	10	10
Predators and wildlife	Yes	2.5	2.5
Chemical use	Yes	5	5
Feed	Yes	7.5	7.5
Escapes, animal movements	Yes	10	10
Disease	Yes	10	10
Source of stock	Yes	10	10
Other—(e.g., GHG emissions)	No	Not relevant	n/a
Total			**72.5**

C1 Data Final Score	**8.06**	**GREEN**

Brief Summary

Most of the assessed criteria have moderate or large amounts of data available. But, due to the small scale of the U.S. shrimp aquaculture industry, data gaps exist in such areas as predator/wildlife interactions and chemical use. The author of this Seafood Watch report has extensive experience in the U.S. shrimp farming industry and relied on this experience throughout the assessment when necessary. The numerical score for Criterion 1—Data is 8.06 out of 10.

Justification of Ranking

The author of this Seafood Watch report worked with the USDA Trade Adjustment Assistance Program from 2004 to 2013 as a business planning specialist for U.S. shrimp farms and had an opportunity to work with most of the U.S. shrimp farmers on the farms.

Two of the categories scored 7.5/10 for data quality and availability. Full data are not available for some categories due to the small size of the industry in the United States. Five categories had more up-to-date and specific data available (Industry or production statistics, Locations/habitats, Escapes and animal movements, Disease, and Source of stock) and scored 10 because of the ease in locating the information and its availability to the public. A current source of data on *L. vannamei* production in the U.S. can be found on the Texas Aquaculture Association URL: www.texasaquaculture.org, Treece 2014. A continuous source of information can be found on Bob Rosenberry's Shrimp News International URL: http://www.shrimpnews.com/. Occasionally, the USDA conducts a nationwide aquaculture survey that gathers a great deal of valuable information. The first survey was conducted in 1995, the second in 2005, and the most recent USDA aquaculture survey was conducted in 2009 (USDA 2005 and 2009).

Further information on shrimp production in Texas was obtained from Dr. Ya-Sheng Juan, of Texas Parks and Wildlife in Brownsville, Texas. The yearly production data from shrimp farms is a requirement of the exotic species permit in the state. Some aquaculture magazines have also published recent articles on shrimp aquaculture in the U.S. These publications include Aquaculture North America, Fish Farming News, The Global Aquaculture Alliance Advocate, Aquaculture International, and World Aquaculture Magazine. Texas Saltwater Fishing Magazine reported on the Texas Parks and Wildlife's Shrimp Inspection Program in May 2010 (TSFM 2010).

Information on effluent discharges was obtained from the Texas Commission on Environmental Quality, which posts on its website the farms that are and are not in compliance with effluent regulations (Texas Commission on Environmental Quality (TCEQ) 2013a). Goodland and Daly (1996), Hopkins et al. (1995), EDF (1997), Folke et al. (1998), Texas Senate Natural Resources Interim Subcommittee (1996), Texas Water Resources Institute (1997), and Goldberg (2001) discussed the environmental effects of shrimp aquaculture. Information on shrimp feed (Rangen 2013) was relatively easy to obtain from producers, feed manufacturers, and the scientific community Both Effluent and Feed received Criterion 1—Data scores of 7.5/10.

Locations/habitats information was readily available and received a high score on data quality. Elevations of the farms can be found on Google Earth. Additional information was found in Boyd 1997, Paez Osuna 2001, Folke and Kautsky 1992, and Stickney 2002.

The poorest score for data quality was for Predators and wildlife, receiving a 2.5/10. This lower score is due to known lethal methods being used to control birds (based on the author's experience) and difficulty in finding that information. One such report on lethal methods to control birds in aquaculture was published by ENN, 1998. The Environmental Defense Fund reported 51,373 predator bird species were killed between 1989 and 1993. The reason for the predator bird mortalities is the birds feeding on the easy pickings that aquaculture provides. These are only the reported statistics of authorized kills (EDF 1995).

The FDA publishes a list of approved chemicals for aquaculture (that can be used without a permit), which is readily available to the public on the FDA URL (FDA 2013). But, quantities of chemicals used were not available, so a 5/10 is given for Chemical use information availability. Dr. Claude Boyd at Auburn University has numerous publications dealing with the use of lime in shrimp farming (see Boyd 2014 for links to the publications).

Escapes and animal movements received a 10/10 because data indicate that neither has been an issue since the 1990s and state regulatory agencies monitor both escapes and animal movements carefully (U.S. Senate Hearing on Marine Shrimp Farming 1996, Joint Subcommittee on Aquaculture (JSA) Report 1997, Texas Parks and Wildlife Department 1997, and FAO 2011). The data are readily available upon request from both state and federal agencies involved with animal movements across borders. All state and federal regulatory agencies require that shrimp must come from a "certified disease-free" hatchery.

Disease scores 10/10 because disease information on the U.S. industry is well published. For example, Texas Parks and Wildlife Department (TPWD) does a bimonthly shrimp health assessment at all coastal shrimp farms and makes these data publicly available on the Texas Parks and Wildlife Website. There are public announcements made if actions are required by TPWD. None of the major shrimp viruses have been reported at coastal farms since 2004, and information on shrimp diseases such as *Vibrio* spp. can be found in the public domain (Overstreet et al. 1997, Nunan et al. 1998, Lightner 1996, Lightner 1998, Lightner 2011, Lightner 2012). If postlarvae come from other countries, then the hatchery has to be certified as disease free by sending monthly samples of the shrimp to a designated shrimp disease laboratory in Arizona. All this information is available to the public and was easily obtained during the course of research for this assessment from the TPWD web site. Also, TPWD has published their hatchery requirement protocols on their website. Dr. Don Lightner, at the University of Arizona, has published extensively on shrimp disease in scientific literature.

Lastly, Source of stock received a score of 10 because all the shrimp farmed in the U.S. come from genetically selected, hatchery-reared broodstock with "High Health" specific-pathogen-free (SPF) status, and the hatchery biosecurity measures do not allow for wild stock mixing. The information on these stocks is available in the public domain and has been published through a number of different outlets, such as USDA U.S. Marine Shrimp Farming Program (1976–2011), Pruder (1992), Wyban and Sweeney (1991), and Moss et al. (2005a).

Overall, Criterion 1—Data quality and availability received a final numerical score of 8.06 out of 10.

Criterion 2: Effluents

Impact, unit of sustainability and principle

- *Impact: aquaculture species, production systems and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms or industries contributes to local and regional nutrient loads.*
- *Sustainability unit: the carrying or assimilative capacity of the local and regional receiving waters beyond the farm or its allowable zone of effect.*
- *Principle: aquaculture operations minimize or avoid the production and discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges beyond the immediate vicinity of the farm.*

Effluent Evidence-Based Assessment

C2 Effluent Final Score	**8.00**	**GREEN**

Brief Summary

U.S. shrimp aquaculture utilizes principally pond production systems with infrequent water exchange, mitigating the downstream effluent impacts. Data show no evidence of adverse effluent impacts from U.S. shrimp farms today. In addition, best management practices coupled with strong federal and state regulations and enforcement further reduce the risk of environmental impacts from effluents. The numerical score for Criterion 2—Effluent is 8 out of 10.

Justification of Ranking

The majority of shrimp farm operations in the U.S. utilize pond production systems that exchange water only at harvest or utilize closed-culture RAS. State regulations stipulate that wastewater must be treated before being released into state waters (or not released at all). To meet this requirement, farmers use constructed settling ponds/wetland filtration systems for water discharged from the pond systems; this represents proper sludge disposal as defined by the Seafood Watch Aquaculture criteria.

Nutrients, organic matter, and suspended solids in effluents can cause negative environmental impacts in coastal waters. There were legitimate concerns raised about Texas shrimp farms in the 1990s (EDF 1995, Baker 1997): siltation and accidental animal releases have historically occurred (e.g., the Arroyo Aquaculture Association [formerly Taiwan Shrimp Farm Village]), and these impacts resulted in heavy fines levied ($63,000) and the adoption of state regulations imposed on discharge limits and other measures to mitigate the escape risk of exotics (Hager 1998).

The Environmental Defense Fund and the Pew Oceans Commission assessed U.S. shrimp farming and published several reports on their findings (Goldburg 2001). The World Wildlife Fund also began assessing shrimp aquaculture and offered best management practices (BMPs) to mitigate the environmental impacts of effluents (Clay 2001). There have been many additional groups, both academic and commercial, working toward helping shrimp farming mitigate the environmental impacts of effluents (Boyd 2001, Stickney 2002, Treece and Hamper 2000, Teichert-Coddington et al. 2000, Paez Osuna 2001, Global Aquaculture Alliance (GAA) 1999, Whetstone et al. 2002, Treece 2002 and many others).

Fertilizers are used routinely in shrimp culture to promote primary and secondary food chain productivity (algae, diatoms, and zooplankton), which shrimp feed upon during their early life stages. The algae also shades the pond and helps control temperature, pH, ammonia, and predation (by making the growing shrimp less visible from above the surface of the water). Some examples of inorganic fertilizers used are sodium nitrate, diammonium phosphate, triple phosphate, and sodium metasilicate. Cottonseed meal is often used in the U.S. to fertilize ponds. Urea and organic fertilizers such as chicken manure are used much less in the U.S. than in other countries. One environmental concern of fertilizer use is that this practice can cause eutrophication in downstream waters. Many of the U.S. farms reuse and recycle water so that the economic value and efficacy of fertilizer use is maximized and the environmental impacts are minimized.

By reducing water exchange, the amount of effluent released during the crop grow-out can be greatly reduced. But, at present, the technology for harvesting shrimp without draining ponds is not available, and ponds must either be drained or the water must be moved from one pond to another. Suggested steps to reduce the concentration of potential pollutants in shrimp pond effluents were given by Boyd (2001): 1) use good management practices during the grow-out period; 2) discharge the final 20% to 25% of the pond effluent as slowly as possible to minimize re-suspension of solids from the pond bottom; 3) pass the effluent through a sedimentation basin; 4) construct, maintain, and operate drainage canals to minimize erosion of the sides and bottoms of these conduits; and 5) prevent erosion at the final outfall of the farm.

Drainage is generally accomplished through standpipes in ponds or catchment basins with a minimum of three screens to prevent shrimp being discharged with the effluent. Discharge is generally carried off the farm via drainage canals. A settling canal, baffle system, and mechanical aeration may be required for discharge limits to be met. Discharges at shrimp farms are monitored both physically and electronically with sensors (pH, dissolved oxygen), and site-specific water discharge limits are established at each coastal farm. Each coastal shrimp farm is permitted individually in Texas; however, all inland farms fall under the TCEQ's "General Aquaculture Rule."

General permit requirements for water discharge from aquaculture and requirements for obtaining coverage under General Permit TXG130000 for the discharge of wastewater from an aquaculture facility can be found on the TCEQ web site. Links to the general permit, relevant forms, and instructions for the Texas Pollutant Discharge Elimination System (TPDES) General Permit No. TXG130000 (renewed on April 18, 2011), can be found at URL: www.tceq.texas.gov. More specifically under URL:
http://www.tceq.texas.gov/permitting/wastewater/general/TXG13_steps.html
(last accessed Oct. 16, 2013).

One such coastal farm's discharge was monitored from May to October and compared to surrounding waters. Table 3 shows the results of the effluent monitoring.

Table 3: Discharge water data compared to receiving waters.

Parameter Tested	Ponds	Range	Bay	Range
Total Suspended Solids (TSS)	66.1	30–131	157	93–230
Inorganic Suspended Solids (ISS)	50.3	21–111	142.7	86–209
Volatile Suspended Solids (VSS)	15.8	7–26	14.3	7–26
Carbonaceous Biological Oxygen Demand (CBOD)	8.6	4–13	5.2	2–10

Notes:
All readings in ppm.
TSS: suspended solids in water lowered by settling for a set period of time and flow velocity reduced.
ISS: those solids such as clay particles that do not burn off in an oven.
VSS: those suspended solids such as algae that do burn off in an oven.
CBOD: a method of measuring organic load in water.
(Source: Dr. David Dunseth, Seaside Aquaculture, Palacios, Texas. Dr. Dunseth is now retired.)

More information concerning discharge criteria at Texas shrimp farms can be found at the TCEQ URL: http://www.tceq.state.tx.gov.

Earlier problems with effluent discharge along the Texas coast, the U.S.'s largest shrimp-producing area, have been largely solved by the introduction and widespread use of recirculating techniques (Cascorbi 2004, Stickney 2002, Treece 2002, Treece and Hamper 2000). In addition , as shown by Cascorbi (2004), there has been little problem with effluent discharge or nutrient pollution from shrimp farms in Hawaii.

Better management practices or best management practices (BMPs) have been used in several countries to establish more general principles of environmentally responsible shrimp farming. The shrimp farming industry in the U.S. has made significant advancements in developing BMPs.

Experience has shown that well-designed and well-implemented BMPs can support producers to:

- Increase efficiency and productivity by reducing the risk of shrimp health problems
- Reduce or mitigate the impacts of farming on the environment
- Improve food safety and quality of the shrimp farm product
- Improve the social benefits from shrimp farming and its social acceptability and sustainability.

BMPs can be country-specific, or developed for a particular location, taking into account local farming systems, social and economic contexts, markets, and environments. For example, in India, experiences have shown that, although principles are widely applicable, BMPS have considerable local variations. BMPs are often voluntary practices, but can also be used as the basis for local regulations, or even certification programs. In Florida, state law (see Florida Statutes Chapter 570) requires that shrimp farms and other aquaculture operations register with the Florida Department of Agriculture and Consumer Affairs. The Certificate of Registration costs USD 50 and requires that the farmer agree to follow the Department's "best management practices" (BMPs). If the farmer follows the BMPs, the Department of Environmental Protection is prohibited from charging the farmer with environmental violations (such as the discharge of sewage or effluent) into surface waters.

The implementing rules (see Florida Administrative Code Chapter 5L-3) do not require aquafarmers "to follow the effluent treatment BMPs" if they use "recirculation systems" or "do not discharge to waters of the state"—in those cases, they are labeled as having a "minimal impact on the surrounding environment." Even if they do not meet those exceptions, the BMPs for effluent treatment require only a retention, evaporation, or percolation pond, or a vegetated filter strip.

Based on federal regulations in combination with state regulations, the "regulatory or management effectiveness" in the U.S. is considered high. Effluent regulations are scientifically robust and specific to aquaculture operations, and site-specific limits to discharges, effluents, and biomass are set to cover the entire production cycle (Environmental Protection Agency [EPA] 2012, TCEQ 2013a). Water quality measures (with limitations in place and set collection times) that must be collected under the "Texas Commission on Environmental Quality General Permit to Discharge Wastes" (TCEQ 2013b) include flow; total suspended solids, inorganic suspended solids, total residual chlorine, pH, dissolved oxygen, carbonaceous biochemical oxygen demand, and ammonia nitrogen. Cumulative impacts are addressed as a control point in Section 309 of the Coastal Management Plan (CMP) along with secondary impacts of development (Texas General Land Office 2011). The EPA also requires all shrimp farms discharging into public waters to have their effluent tested for heavy metals; mainly copper and selenium. The EPA requires each coastal farm to send a water sample (55-gallon barrel) to the EPA lab for testing, where a toxicity test on the water is run using *Daphnia*, a well-known zooplankton commonly used for lab tests. Each farm is required to pay for the water testing, which generally costs $10,000/year/discharge point (pers. comm., shrimp farmers Reed Bowers and Fritz Jaenike).

All Texas coastal shrimp farms are individually permitted. If the farm is located within the coastal plain, it must be individually permitted by the Texas Commission on Environmental Quality. If water is discharged into public waterways, then that water must be equal to or better than the receiving waters (TCEQ 2013b). This is also an Environmental Protection Agency (EPA) National Pollution Discharge Elimination System (NDPES) requirement (EPA 2012).

Enforcement is also shown to be effective. For example, the Texas Department of Agriculture holds authority for the regulation of aquaculture in Texas and issues fish farming permits. Permitting and enforcement organizations include the Environmental Protection Agency (EPA), Texas Commission on Environmental Quality (TCEQ), and Texas Parks and Wildlife Department (TPWD), U.S. Fish and Wildlife Service, and U.S. Army Corps of Engineers (Treece 2005). Penalties for infractions of the Texas Agriculture Code and the TCEQ General Permit to Discharge Waters are clearly identified in Section 134.023. Penalties and charges for infringements range from misdemeanor to felony charges (Texas Agriculture Code 2007). The EPA publishes online its enforcement cases with the name of the respondent, description of the alleged violation, and the penalty amount (EPA 2012). The TCEQ supplies monthly enforcement reports (TCEQ 2013a) and reported numerous on-site investigations in 2012. Further, they also reported the percent of permitted facilities in compliance with permits, enforcement orders, or programs per annum. In 2012, it was reported that 99% of all “water facilities” inspected were in compliance (TCEQ 2013a).

Data show no evidence that effluents contribute to impacts beyond the immediate vicinity of the farm or discharge points. In addition, best management practices coupled with effective management and enforcement are demonstrably efficient in avoiding any significant effluent impacts. Thus, using the evidence-based assessment option, the numerical score for Criterion 2—Effluent is 8 out of 10.

Criterion 3: Habitat

Impact, unit of sustainability and principle

- *Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical “ecosystem services” they provide.*
- *Sustainability unit: The ability to maintain the critical ecosystem services relevant to the habitat type.*
- *Principle: Aquaculture operations are located at sites, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats.*

Criterion 3: Habitat

Habitat parameters	Value	Score	
F3.1 Habitat conversion and function		9.00	
F3.2a Content of habitat regulations	5.00		
F3.2b Enforcement of habitat regulations	4.75		
F3.2 Regulatory or management effectiveness score		9.50	
C3 Habitat Final Score		**9.17**	**GREEN**
Critical?	NO		

Brief Summary

The majority of U.S. shrimp farms were converted from terrestrial crop farms, and no sensitive or high-value habitats are affected by U.S. shrimp aquaculture. Minimal habitat impacts have occurred, but no overall loss of habitat functionality has been experienced. Robust federal and regional legislation and enforcement prohibit significant habitat impacts from occurring. Thus, the Criterion 3—Habitat score is 9.17 out of 10.

Justification of Ranking

Factor 3.1 Habitat conversion and function

Aquaculture operations in the U.S. are regulated at both the federal and state levels, and site selection, habitat, and habitat destruction (or mitigation) are considered in permit applications, reviews, and rulings. Shrimp farms have resulted in minimal habitat impacts with no overall loss of habitat functionality.

In the U.S., habitat modification for shrimp farming has been quite minor (Stickney, 2002). The climate and costs prohibit wide-scale development of shrimp farms in the U.S. (GAA 1999), with the result that this industry has little potential for expanded growth beyond its current production.

Many shrimp farms have been converted from terrestrial crop farms. For example, two of the largest farms in Texas were terrestrial crop farms (cotton, milo, and rice) before they were converted to shrimp farms. At KAAPA Farms in Bayview, TX, citrus crops, cotton, milo, and melons were grown on the site before the shrimp farm was built in 1980. Bowers Shrimp and Catfish in Collegeport, TX was a rice field before being converted to a shrimp and catfish farm.

The habitat used for freshwater pond aquaculture can be reclaimed. For example, many catfish farmers converted their catfish ponds back to cattle grazing land when the economics of cattle became more favorable than catfish. Others have reverted their ponds to terrestrial crop farming because it is more economically viable.

There has been a long-standing misconception that shrimp farms in the U.S. are built in the intertidal zones. Although this has historically occurred in some developing countries and resulted in mangrove destruction, U.S. shrimp farms are built in the intertidal zones and are high enough to ensure that they will drain completely at harvest.

The majority of shrimp pond acres in the U.S. are located near the coast and are considered high-value "coastal-inshore" habitat by the Seafood Watch criteria. Nailon (2003) placed a habitat value of USD 6,000 per acre on the Texas salt marsh. Texas shrimp farms are located above the salt marshes at a higher elevation and away from sensitive nursery areas and estuaries. Ponds would not gravity-drain if they were located in the salt marsh, so they are generally at a higher elevation so the ponds will drain. Also, these sensitive areas that the ponds drain into are protected by discharge regulations that do not allow silt to cover grass beds, etc. King and Lester (1995) showed the value of salt marsh as a sea defense. Further values of the salt marshes of the U.S. are given at URL: http://www.greatmarsh.org/

In addition, the discharge areas of shrimp farms provide improved habitat for bait fish, such as mullet, shad, and minnows. Other fish utilize these concentrations of bait fish, as do recreational fishers. Created wetlands have also been used at coastal shrimp farms with success, and duck hunters enjoy the benefits afforded by these areas. Aquatic plant life such as *Rupia*, *Spartina*, duck weed, cattails, wigeon grass, mangroves, and others flourish in these constructed wetlands.

The numerical score for Factor 3.1 is 9 out of 10, indicating minimal habitat conversion and only minor impacts on ecosystem functionality.

Factor 3.2. Habitat and farm siting management effectiveness (appropriate to the scale of the industry)

Aquaculture operations are regulated at both the federal and state levels, and site selection, habitat, and habitat destruction (or mitigation) are considered in a permit application, review, and ruling. The USDA's Aquaculture Act of 1980 (Buck and Becker 1993) and EPA regulations apply, as well as the state rules and regulations on aquaculture (listed individually for each state below). The Clean Water Act (CWA) was established in 1972 and last updated May 20, 2013 by the Environmental Protection Agency (EPA) (CWA 2013). Section 404 of the CWA is enforced by the U.S Army Corps of Engineers (USACE) and requires a permit for any dredging, construction of intake structures, and any wetland use or habitat destruction. Further, under most states' coastal management plans (CMP), there is generally a "no net loss of wetlands" policy in place, encouraged by the EPA and the U.S. Fish and Wildlife Service. In the period 2006–2011, some 12,932 acres of wetland were regained through voluntary measures built by many different entities, including shrimp farms. There is no guarantee that wetland habitat is completely safe from all aspects of development, but this does suggest that a culture of wetland preservation exists. Data on loss of wetlands are not available because a U.S. Supreme Court decision removed wetlands as part of navigable waters and also removed them from permit requirements (Texas General Land Office 2011). For example, as part of the permitting process in Texas, cumulative impacts are addressed as a control point in Section 309 of the CMP, along with secondary impacts of development (Texas General Land Office 2011). Although cumulative impacts are addressed, overall ecosystem function is not. If there were new shrimp farms being built on the U.S. coast, there could be increased habitat concerns; however, there have been no new shrimp farms built in several years and none are planned in the near future that would affect habitat on the U.S. coast.

The shrimp aquaculture permit process is quite stringent for any coastal zone in the U.S., and no new coastal shrimp farms have been licensed in the last 10 years. This is partly the result of the strict permitting process and the economic expense of providing all the documentation and materials required by the applicant, including public hearings. The difficulties of aquaculture permitting in Gulf and South Atlantic U.S. states were discussed by Maxwell et al. (2006).

The only shortfall in the established regulations is that ecosystem function is not always considered as part of the assessment for farms. The coastal farms in Texas were terrestrial crop fields before they were converted to shrimp farms. But in other countries, this is not the case. For example, mangroves were lost in Ecuador at the expense of shrimp farming, and are now being replanted.

Shrimp Aquaculture Regulations in the U.S.

U.S. shrimp aquaculture operations are regulated by the U.S. Department of Agriculture’s (USDA) Aquaculture Act of 1980 (Buck and Becker 1993), as well as the U.S. Environmental Protection Agency (EPA) regulations (EPA, 2012). Enforcement and consequences of infractions are clearly defined by EPA and data are made available to the public. In addition , the General Land Office of Texas has authority to regulate all submerged waters of the state and controls leasing bottom rights. Their Section 309 of the Texas coastal management program describes their role (Texas General Land Office 2011).

Selected examples of existing U.S. regulations relevant to shrimp farms can be found in Appendix 1 of this report.

Final Score for Criterion 3

Factors 3.2a and 3.2b score 5 out of 5 and 4.75 out of 5, respectively. The overall score for Factor 3.2 is 9.5 out of 10.

The final numerical score for Criterion 3—Habitat is 9.17 out of 10.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- *Impact: Improper use of chemical treatments impacts non-target organisms and leads to production losses and human health concerns due to the development of chemical-resistant organisms.*
- *Sustainability unit: Non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to important treatments*
- *Principle: Aquaculture operations by design, management or regulation avoid the discharge of chemicals toxic to aquatic life, and/or effectively control the frequency, risk of environmental impact and risk to human health of their use.*

Criterion 4 Summary

Chemical Use parameters	Score	
C4 Chemical Use Score	**6.00**	
C4 Chemical Use Final Score	**6.00**	**YELLOW**
Critical?	NO	

Brief Summary

Disease outbreaks are uncommon in U.S. shrimp aquaculture, so the need for chemical use is demonstrably low. The most common chemical used is agricultural lime, which is often used to disinfect pond bottoms after harvest. Although select instances of chemical use have historically occurred, best management practices currently mitigate the risk of disease outbreaks and minimize the need for chemical use. The final numerical score for Criterion 4—Chemical Use is 6 out of 10.

Justification of Ranking

In general, though chemical use is known to be low in U.S. shrimp aquaculture, publicly available scientific information is limited. The author of this assessment has relied on personal communications with producers as well as extensive personal experience as outlined in the following text. Boyd (2009) published "Calculating Chemical Treatments for Aquaculture," which suggested specific amounts of substances to apply to ponds if needed.

Regulations prohibit the use of many chemicals and antibiotics in U.S. shrimp aquaculture. The FDA in Silver Spring, MD publishes a list of drugs approved for aquaculture, USFDA URL: http://www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/Aquaculture/ucm132954.htm. The main commercial operations in the U.S. claim that they use chemicals and antibiotics responsibly and only when necessary. Although unsubstantiated, this claim is reinforced by limited or no disease occurrences in recent history in the U.S., negating the need for chemical use. Agricultural lime is used to control algal blooms and bacterial infections in shrimp, such as *Vibrio* spp. Lime is also used to adjust the soil pH or to disinfect soils between crops. It can also be used directly in the pond during grow-out to control "black spot" on shrimp, an ailment caused by chitin-eating bacteria on the shell. Boyd (2002) described the correct liming procedures and amounts to use to improve shrimp pond water and bottom quality. In 2003, Boyd described chemical fertilizers in pond aquaculture.

It is considered acceptable practice to use agriculture lime to disinfect pond bottoms between crops. This practice is used worldwide and is shown to have minimal effects on surrounding habitats at the levels suggested for use by most best aquaculture practices (BAPs). Typical lime rates that have been used on shrimp farms to adjust soil pH, to disinfect and oxidize metabolic wastes left on the pond bottom, and to address other water quality issues are discussed by Boyd (1990).

Although the use of lime is commonplace and does not require a permit, other chemicals are regulated more closely and their use is permitted on a case-by-case basis. For example, an infestation of tube worms (*Chaetagnaths*) became a problem on one of the shrimp farms in South Texas, and a special pesticide application was requested and approved by the TCEQ. The false mussel was another intruder that was introduced and grew on all structures underwater (paddle wheel aerators, effluent pipes, and water control gates) to the point that the sharp-edged shells became dangerous for workers. No control measures were taken for the false mussel other than mechanical measures (manually scraping off pipes and other structures).

Generally, U.S. shrimp farms work to avoid disease, and the subsequent need for chemical use, through best management practices and good husbandry; however, chemical use is necessary on occasion. For example, if black spots are seen on the shrimp shells, the first course of action is to add molasses to the ponds as a carbon source to promote beneficial bacteria and control against the detrimental bacteria. If this is ineffective at combating the black spot, lime is added to the pond in an attempt to disinfect and control the bacteria causing the black spots.

Post-harvest, meta-bisulfite is often used at 2 ppm dip for 2 minutes to stop the normal chemical process that turns the shrimp shell dark after harvest. After a woman died in Corpus Christi, Texas in the 1980s from an allergic reaction to bisulfite in wild harvested shrimp, the FDA established a regulation that no more than 100 ppm bisulfite could be found in shrimp muscle. The FDA requires that all shrimp must be appropriately labeled if they contain bisulfite—this is similar to the wine and lettuce industries, which also use the same chemicals during processing for similar reasons.

The TCEQ's General Permit to Discharge Wastes (TCEQ 2013b) requires that the use of any chemical, drugs, or antibiotics is reported to the TCEQ. Given the data available, chemical use in U.S. shrimp farms is best defined by the Seafood Watch criteria as "Specific data may be limited, but the species or production systems have a demonstrably low need for chemical use." The final numerical score for Criterion 4—Chemical Use is 6 out of 10.

Criterion 5: Feed

An interim update of this assessment was conducted in July 2022. This criterion was updated with new information. The interim update can be found in Appendix 4 at the end of this document.

Impact, unit of sustainability and principle

- *Impact: feed consumption, feed type, ingredients used and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and their efficiency of conversion can result in net food gains, or dramatic net losses of nutrients. Feed use is considered to be one of the defining factors of aquaculture sustainability.*
- *Sustainability unit: the amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.*
- *Principle: aquaculture operations source only sustainable feed ingredients, convert them efficiently and responsibly, and minimize and utilize the non-edible portion of farmed fish.*

Criterion 5 Summary

Feed parameters	Value	Score	
F5.1a Fish In:Fish Out ratio (FIFO)	2.16	4.60	
F5.1b Source fishery sustainability score		–4.00	
F5.1: Wild Fish Use		3.74	
F5.2a Protein IN	39.95		
F5.2b Protein OUT	14.42		
F5.2: Net Protein Gain or Loss (%)	–63.91	3	
F5.3: Feed Footprint (hectares)	14.74	5	
C5 Feed Final Score		**3.87**	**YELLOW**
Critical?	NO		

Brief Summary

Commercial U.S. shrimp aquaculture achieves a feed conversion ratio (FCR) of 1.80 by utilizing feeds with 25% fishmeal inclusion and 6% fish oil inclusion. The fish in:fish out (FIFO) ratio is 2.16 and is relatively high compared to shrimp culture outside the U.S. The principal source fishery for fishmeal and fish oil is the Gulf menhaden, which has a Seafood Watch ranking of Yellow. U.S. shrimp aquaculture results in a significant net loss of protein (–63.91%), and a total feed footprint of 14.74 hectares of land and ocean area is required to produce the feed ingredients required to grow one ton of shrimp. The final Criterion 5—Feed score is 3.87.

Justification of Ranking

Factor 5.1. Wild Fish Use

Fishmeal and fish oil inclusion levels are readily available from commercial producers and researchers, and from feed mills upon request. Sources that were queried all reported similar inclusion values: 25% fishmeal inclusion and 6% fish oil inclusion. A realistic commercial shrimp feed conversion ratio (FCR) reported (pers. comm., Reed Bowers, Texas and Dr. David Teichert-Coddington, Alabama 2013) was 1.80 (1.8 lb of feed for every 1 lb of shrimp produced). Numerous academic sources reported lower FCRs ranging from 1.15 to 1.8 (Samocha et al. 2004, Markey 2010, Samocha 2012, among others); however, an FCR of 1.80 was used for this assessment. Because no information on the inclusion of fishmeal or fish oil from processing by-products was available, this assessment has assumed a value of 0 for these inclusions.

Factor 5.1a. Fish in to fish out ratio (FIFO)

The U.S. shrimp aquaculture industry is still heavily dependent upon fishmeal as a source of protein in shrimp diets. Some replacements for fishmeal have been found by researchers such as Dr. Alan Davis at Auburn University and Dr. Tzachi Samocha at Texas A&M University, but the monetary cost of these replacements is still high, so there is little economic incentive for producers to change their feed formulations. The research and development of fishmeal replacements seems promising and, with time, it is expected that fishmeal will be replaced by alternative sources of protein at a cost savings.

Fish in:fish out (FIFO) was calculated based on the fishmeal and fish oil inclusion values provided by both shrimp producers and feed manufacturers. These calculations are shown below. Note that fishmeal and fish oil yield values were not available, so global averages provided by Tacon and Metian (2008) were utilized.

FIFO Fishmeal = ([fishmeal inclusion level] × [economic FCR]) ÷ (fishmeal yield)
FIFO Fishmeal = ([25] × [1.8]) ÷ (22.5) = 2.00

FIFO Fish Oil = ([fish oil inclusion level] × [economic FCR]) ÷ (fish oil yield)
FIFO Fish Oil = ([6] × [1.8]) ÷ (5) = 2.16

Greater of the 2 FIFO values = 2.16

Final FIFO score = 10 – (2.5 × FIFO) = 10 – (2.5 × 2.16) = 4.60

The FIFO score is driven by the FIFO value for fish oil, and the final numerical score for Factor 5.1a is 4.60. This score may be adjusted depending on the sustainability of the source fisheries as outlined in Factor 5.1b below.

Factor 5.1b. Source fishery sustainability

Menhaden from both the Gulf of Mexico and the South Atlantic are the principal species utilized for both fishmeal and fish oil in U.S. shrimp feeds. The Peruvian anchoveta is also a source of fishmeal used in shrimp diets; however, the Peruvian source is more expensive and is used only if menhaden meal and oil are not available. According to FishSource (2013b), the U.S. Gulf of Mexico menhaden fishery is managed under a cooperative plan of the five Gulf Coast States, with coordination and scientific guidance provided by the Gulf States Marine Fisheries Commission, which includes representatives from each Gulf State. The Commission develops and maintains regional fishery management plans for major fisheries shared by the states, operating under the Inter-jurisdictional Fisheries Act of 1949. Also, according to FishSource (2013b), there is no Gulf-wide catch limit for Gulf menhaden, and Texas (a minor producer) adopted its own catch quota that went into effect in 2009. The latest stock assessments in the menhaden industry indicate that it is not overfished. The fishery management plan notes that "comparisons of recent estimates of fishing mortality to biological reference points do not suggest overfishing" (Vanderkooy and Smith 2002). The history and structure of the fishery—with accurate catch records, a small fleet, only a few landing ports, relatively stable productivity, and a relatively consistent relationship between measured effort and catch—suggest that harvests have been well regulated. Also with the Gulf fishery, one can compare the Vaughan et al. (2007) menhaden stock assessment report to the Vaughan et al. (2011) report and see a similar pattern of stability in the industry, even when considering the 2010 Deepwater Horizon oil spill.

U.S. menhaden has a Seafood Watch ranking of Yellow, resulting in a Factor 5.1b Source Fishery Sustainability adjustment score of –4 out of –10. When this adjustment score is combined with the Factor 5.1a score, the final score for Factor 5.1 is 3.74 out of 10.

Factor 5.2. Net Protein Gain or Loss

Starter feeds for juvenile shrimp contain 45% total protein, but are used only for about one month. The U.S. shrimp farms currently in operation use 32% to 35% total protein feeds for the majority of the shrimp production cycle. The higher protein level (35%) was used in this assessment.

Despite natural productivity in the ponds, a 35% protein diet is generally required in intensive and super-intensive culture systems. Providing the proper amount of dietary energy relative to protein (and other nutrients) is critical to ensure adequate nutrient intake, maximize the use of dietary protein for protein synthesis, and reduce ammonia excretion in shrimp (New 1987).

Table 4 shows practical diet formulations that meet all known requirements of marine shrimp nutrition.

Table 4: Model formulations of practical shrimp feeds for intensive culture (38% crude protein) and semi-intensive culture (30% crude protein)

Ingredients, g/100 g	38%	30%
Fishmeal	16	12
Shrimp head meal	15	10
Squid meal	5	0
Soybean meal	30.8	28.6
Cereal products or by-products	22–24	39–41
Fish oil	4	4
Soybean lecithin	1	0
Cholesterol	0.2	0
Binder	1–3	1–3
Dicalcium phosphate	2.3	2.7
Vitamin premix	0.5	0.5
Trace mineral premix	0.05	0.05

Taken from: Lim, C. and A. Persyn, Practical Feeding—Penaeid Shrimps,
pp. 205–222 *in* Nutrition and Feeding of Fish, T. Lovell, Chapman & Hall, New York, NY.

Data on use of non-edible feed sources and feed protein from crops were readily available from Dr. Allen Davis, Auburn University (pers. comm., 2013) and were the same as the average assumed values reported by Tacon et al. (2011). In both cases, the commercial feed in the U.S. had, on average, 26% non-edible by-products, and this value was utilized for this assessment. The protein from crops was also assumed to be an average value of 37% as provided in Tacon et al. 2009. The average protein content of whole harvested shrimp (17.8%) was taken from the Seafood Watch scoring tool. The edible yield of the whole harvested shrimp is 62% to 65%, depending upon the method used to remove the head. The lesser yield (62%) is used for this assessment. Finally, the percentage of non-edible by-products from harvested farmed shrimp used for other food production was 50% (Tacon et al. 2009) (personal experience by the author in shrimp processing plants since 1978) (pers. comm., Harvey Persyn 2014) (pers. comm., Albert Tacon 2014).

Protein In = {protein content of feed – [protein content of feed × (percentage of feed protein from non-edible sources + 0.286 × percentage of feed from edible crop sources) ÷ 100]} × FCR.
Protein In = {35 – [35 × (26 + 0.286 × 37) ÷ 100]} × 1.8 = **39.95**

Protein Out = (protein content of whole harvest farmed shrimp ÷ 100) × [edible yield of harvest farmed shrimp] + [percentage of non-edible by-products from harvest farmed fish used for other food production] × [100 – edible yield of harvested farmed shrimp] ÷ 100].
Protein Out = (17.8 ÷ 100) × (62 + 50) × (100 – 62) ÷ 100] = **14.42**

Net protein gain or loss = (Protein Out – Protein In) ÷ Protein In
Net protein loss = (–25.53) ÷ 39.95 = **–63.91%**

U.S. farmed shrimp culture results in a net loss of protein. With 64% protein lost, the numerical score for Factor 5.2 is 3 out of 10, or Yellow.

Factor 5.3. Feed Footprint
Data were available on the inclusion of edible crop or land animal product ingredients in feed formulations for shrimp culture (pers. comm., Dr. Allen Davis, Auburn University 2013). Edible crop inclusion (32%) was found to be the same as reported by Tacon et al. (2011). Marine ingredients have higher primary productivity requirements than land animal ingredients or crop-based ingredients; therefore, the greater the component of the feed from crop ingredients, the lower the overall feed footprint.

5.3a. Ocean area appropriated per ton of farmed shrimp = (inclusion level of aquatic feed ingredients ÷ 100) × eFCR × average primary productivity (carbon) required for aquatic feed ingredients] ÷ average ocean productivity for continental shelf area.
Ocean area appropriated per ton of farmed shrimp = [(31 ÷ 100) × 1.8 × 69.7] ÷ 2.68 = **14.51** ha ocean area ton-1 of farmed shrimp

5.3b. Land area appropriated per ton of farmed shrimp = {[inclusion level of crop feed ingredients + (inclusion of land animal products × conversion ratio of crop ingredients to land animal products)] × 0.01 × eFCR} ÷ average yield of major feed ingredient crops
The land area appropriated per ton of farmed shrimp = {[33.5 + (0 × 2.88)] × 0.01 × 1.8} ÷ 2.64 = **0.23** ha land area ton-1 of farmed shrimp.

Value (ocean + land area) = 14.74 ha ton-1 of farmed shrimp.

With a feed footprint of 14.74 hectares, the numerical score for Factor 5.3 is 5 out of 10.

The final numerical score for Criterion 5—Feed is 3.87 out of 10. The further development and inclusion of fishmeal and fish oil substitutes is likely to improve the Feed score. Many researchers (Davis and Boyd at Auburn Univ.; Samocha, Lawrence, and Gatlin at TAMU; among others) are working to find fishmeal replacement diets that are economical. This research has already started to affect commercial shrimp feed formulations at the major feed companies (Cargill, Zeigler, and Rangen).

Criterion 6: Escapes

Impact, unit of sustainability and principle

- *Impact: competition, genetic loss, predation, habitat damage , spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations*
- *Sustainability unit: affected ecosystems and/or associated wild populations*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations associated with the escape of farmed fish or other unintentionally introduced species.*

Criterion 6: Escapes Summary

Escape parameters	Value	Score	
F6.1a Initial Escape Risk		6.00	
F6.1a Recapture and mortality (%)	25		
F6.1a Escape Risk Score		7.00	
F6.1b Invasiveness		4	
C6 Escape Final Score		**5.00**	**YELLOW**
Critical?	NO		

Brief Summary

Outdoor ponds represent the greatest risk of farmed shrimp escapes. Raised pond dikes, multiple screens at discharge points, and other best management practices mitigate the risk of escape; however, this risk is still considered low to moderate. Although escaped shrimp can interact with wild populations, hybridization and the subsequent deleterious genetic impacts are highly unlikely. The score for Criterion 6—Escapes is 5 out of 10.

Justification of Ranking

Factor 6.1a. Escape risk

Whiteleg shrimp is raised in enclosed earthen ponds and raceways and is heavily regulated as an “exotic species” in all states where it is cultured. Regulations and best management practices have been successful so far in containing potential escapes, which could pose environmental risks to the surrounding environment, especially native shrimp populations. The greatest risk of escape is in outdoor pond-based farms; however, these facilities employ multiple and appropriately sized screens, water treatment, and secondary capture devices. The coastal farms are also required to have pond dikes 1 foot above the 100-year floodplain.

The majority of U.S. shrimp farms (in number, not in acreage) are inland operations using recirculation systems with screens, with no direct connection to natural water bodies. The farms are not subject to flood or storm surge because they are located inland from the coast.

Although hurricanes pose a direct threat to coastal farms of escapes, due to the potential for a storm surge, a hurricane has not affected shrimp farms in the U.S. since the first farm was built in 1980, and farms are required by regulatory agencies to have contingency plans in the event of a hurricane. For example, in Texas, each pond must have three separate (redundant) screens at the effluent discharge point, to prevent escapes. To prevent a potential storm surge from entering ponds, the tops of the pond dikes must be at least 1 foot above the 100-year floodplain, which generally results in the pond dikes being about 15 feet above sea level. Farms are required to either quick-harvest the crop before an oncoming storm or lower the pond water level to prevent excessive rainfall from causing the pond to overflow.

It is also thought that shrimps that successfully escape from ponds have a very high mortality rate, because no farmed-raised shrimp have been found in the wild since the late 1990s when an accidental release occurred at Arroyo City, Texas. Several publications (e.g., Briggs et al. 2004, CABI 2011) have noted that no domesticated *L. vannamei* populations have established in the wild on the Atlantic coast or the Gulf of Mexico, even though shrimp farms have existed there since the 1980s and 1990s. Columbia, Nicaragua, Honduras, Panama, Venezuela, Trinidad, the Virgin Islands, Puerto Rico, the Dominican Republic, the Bahamas, Cuba, and even Mexico's Gulf of Mexico coast have *L. vannamei* farms, and no wild populations have been established (FAO 2011a) (FAO 2011b,) (Briggs et al. 2004) (CABI 2011).

According to FAO (2011), *L. vannamei* is restricted to areas where the water temperature remains above 20 °C (68 °F) throughout the year. This is critical information in determining why this species has not been seen to be invasive outside its normal habitat.

The initial escape risk score (Factor 6.1a) is 6 out of 10, based on low-exchange ponds with multiple or fail-safe escape prevention methods. The escape risk score can be improved by applying a recapture and mortality adjustment when there is evidence of immediate recapture or direct mortality of escapes. Though no scientific studies were available to inform this adjustment, in the author's experience, a large majority of escaped shrimp are expected to experience mortality, based on the species' requirements for high water temperatures and the increased incidence of predators around farms. For the purposes of this assessment, a conservative adjustment of 25% is applied, although in reality a much higher portion of any escapes are not expected to survive long enough to affect surrounding environments.

When the 25% recapture and mortality adjustment is applied, the numerical score for Factor 6.1a is 7 out of 10.

Factor 6.1b. Invasiveness

With respect to Factor 6.1b Invasiveness, *L. vannamei* is considered non-native to the United States. Farmed shrimp are not established in the region, and any escapees are considered highly unlikely to survive or establish viable populations (FAO 2011) (CABI 2011). Thus, Factor 6.1b Part B scores 2 out of 2.5.

CABI (2011) classifies *L. vannamei as* "not-invasive" in all the sea areas that it lists and all the areas of Asia, Africa, North America, Central America and the Caribbean, and South America. The only areas where *L. vannamei* has been introduced that CABI did not classify it as not-invasive are: Netherlands, Fiji, French Polynesia, Guam, and New Caledonia. FAO (2011) states that the species will not survive in areas where the water temperature drops below 20 °C (68 °F). FAO goes further to say that the species is restricted to areas where the water temperature remains above 20 °C (68 °F) throughout the year. This temperature dependency alone rules out any possibility of *L. vannamei* establishing wild breeding populations in U.S. waters, because the climate in the U.S. is considered temperate and not tropical.

There have been a number of physiological studies on the various species of shrimp and how they interact with other shrimp species. Dall et al. (1991) included discussion on *L. vannamei*. Evidence from earlier research at Texas A&M University on crossing various species of shrimp showed that, even though hybridizing species is possible using artificial insemination, the crosses are sterile. It is thought that escapees would compete for habitat and would act to the detriment of other species (e.g., by feeding, foraging, and settlement). No other impact of escapees on native shrimp is known.

Further on the invasiveness factor, researchers attempted to cross the native Gulf of Mexico species with exotic shrimp in the 1980s and 1990s. Some of the crosses were successful, but the offspring were sterile and a viable cross could not be maintained. Hybridization was attempted with *L. setiferus* (Gulf white shrimp) + *L. stylirostris* (Pacific blue shrimp) and other species at Texas A&M University in the 1980s. Cryopreservation of eggs was also attempted with limited success both at Texas A&M University and the University of California, Davis. The results of these studies indicate that successful hybridization between shrimp species is unlikely, so deleterious genetic impacts of farm escapes on wild stocks are of low concern.

In further justification of the invasiveness scoring, an examination of current lists of invasive species published by the International Union for the Conservation of Nature's (IUCN) Invasive Species Specialist Group revealed no listings for *L. vannamei*. As mentioned in the section above, *L. vannamei* has been anthropogenically introduced as an aquaculture species to several areas of the world where it is not native (e.g., United States, Belize, Brazil, various Caribbean and Pacific islands, Southeast Asia, mainland China, and India). Although there have been numerous escapes from aquaculture production facilities into non-native waters, and this species is regularly caught in the wild around Asia, it is as yet unproved whether or not breeding populations have been established anywhere in the world outside the species' natural range (CABI 2011). CABI (2011) labels *L. vannamei* as a "not-invasive" species in all areas listed on its distribution table. Unlike *P. monodon*, *L. vannamei* has not been found to be invasive outside its normal range. FAO (2011) states that the species has a very restricted temperature requirement.

Any escapes that do occur are expected to compete with native populations for food and habitat, as well as add predation pressure on wild populations. Escapees are also expected to modify habitats to the detriment of other species by feeding and foraging. But, as shown from the hybridization studies above, escapees are not expected to compete with native populations for breeding partners or to disturb breeding behaviors or wild shrimp.

The numerical score for Factor 6.1b is 4 out of 10.

Final Escape Score

The Escape Risk and Invasiveness Factors are combined to calculate an overall Escape Final Score. The Escape Risk score (Factor 6.1a, score of 7 out of 10) is driven mainly by the threat of escapement of exotics during a potential storm event. Coastal facilities are at greater risk of escapement due to potential hurricanes than inland facilities are, and the indoor facilities are at less risk of escapement than the open ponds. Although hybridization of farm escapes with wild shrimp populations is unlikely, any shrimp that do escape will affect the surrounding environment in a variety of ways (Factor 6.1b, score of 4 out of 10).

The final numerical score for Criterion 6—Escapes is 5 out of 10.

Criterion 7: Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

- *Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body*
- *Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.*

Criterion 7: Diseases

Pathogen and parasite parameters	Score	
C7 Biosecurity	8.00	
C7 Disease; pathogen and parasite Final Score	**8.00**	**GREEN**
Critical?	**NO**	

Brief Summary

Although several shrimp diseases are problematic in the global industry, the United States has historically had relatively few instances of disease outbreaks and mortality. Some examples of outbreaks are known, but research and development of biosecurity and best management practices have mitigated the risk of outbreak as well as the transmission to wild populations. To date, there is no evidence that diseases from shrimp farms have adversely affected wild populations. The score for Criterion 7—Disease is 8 out of 10.

Justification of Ranking

U.S. shrimp producers report that, even though viruses do not occur on their farms, bacterial infections are common. Outbreaks of *Vibrio* spp. (*harveyi*, *vulnificus*, and *parahimolicitus*) are an ongoing problem in both the intensive outdoor and the super-intensive indoor operations. Treating bacterial infections with chemicals is economically costly and may have adverse environmental impacts; therefore, preventative measures such as best management practices are employed to mitigate the risk of disease outbreaks. Biosecurity for outdoor ponds consists of obtaining disease-resistant animals, preventing any human traffic that might contaminate or spread disease from other farms, and washing and disinfecting cast nets, boats, and other equipment that are shared between ponds.

During the 1990s, the understanding of shrimp diseases, virulence, and containment was limited, so there was justified concern about the spread of shrimp diseases from exotic cultured animals to wild populations in the United States. Through research and development (see Johnson 1991, 1995; Lightner 1999; Alday and Flegel 1999; Brock and Main 1995), biosecurity protocols and best management practices were developed to mitigate these risks. These biosecurity measures have kept the U.S. virus-free since 2004.

Historically, disease outbreaks have occurred on U.S. shrimp farms. An outbreak of white spot syndrome virus (WSSV) first occurred in the U.S. on a Texas shrimp farm in 1995. Taura syndrome virus (TSV) was first found in the Taura River basin in Ecuador and subsequently spread to the United States. It was initially eradicated from the U.S., but another outbreak occurred in 2002. According to USDA/USMSFP, the USDA's High Health program assisted in producing animals that were five times more resistant to TSV than the unimproved animals (pers. comm., Tony Ostrowski, director of the USMSFP in 2003 and current president of the Oceanic Institute in Hawaii). Thus, by the time the second TSV outbreak occurred, the domesticated animals being cultured were more resistant, and effective biosecurity measures were in place to mitigate the virus's impacts. WSSV was effectively eradicated in 1995, and a TSV outbreak has not occurred since 2004. It should be noted that WSSV has continued to cause problems in other countries, such as Mexico, where an outbreak occurred in the state of Sonora in 2010 and continues to cause problems on farms there today. Mexican shrimp hatcheries did not employ any selective breeding for disease resistance, according to personal communication from CIAD (2010) in Sonora.

Environmentalists and shrimp harvest groups lobbied the U.S. Congress to create the Joint Subcommittee on Aquaculture (JSA) in the 1990s. The JSA initiated and paid for an assessment of the threat from shrimp farming to wild shrimp stocks, which was carried out from 1995 to 1997. The resulting report, "Evaluation of Potential Shrimp Virus Impacts on Cultured Shrimp and Wild Shrimp Populations in the Gulf of Mexico and Southeastern U.S. Atlantic Coastal Waters," was submitted to the U.S. Congress by the Joint Subcommittee on Aquaculture (consisting of the U.S. Dept. of Commerce, NOAA/NMFS, USDA, Animal and Health Inspection Service, National Center for Environmental Assessment, U.S. EPA, the U.S. Fish and Wildlife Service, and U.S. Dept. of Interior) in June 1997. In brief, the study concluded that there were threats to wild shrimp populations from farms, but that these threats were minimal due to the steps being taken by the shrimp culture industry to control disease outbreaks. The industry developed disease-free strains of shrimp through the efforts of the USDA's U.S. Marine Shrimp Farming Program, initially headed by Dr. Gary Pruder, then Dr. Anthony Ostrowski, and lastly by Dr. Saun Moss. All three of these directors have numerous publications describing the extensive process of developing disease-resistant animals (Pruder 1992; Ostrowski et al. 2005, 2006; Moss 2007, 2008, 2009; Moss et al. 2005a, 2005b, 2008a, 2008b, 2009). The JSA report concludes that diseases were becoming better understood and procedures were being implemented to avoid or prevent them (JSA 1997). An overall conclusion of the report was that, as the industry technology and practices developed (based on further information on disease control methods), the threat of disease outbreak and transfer was further minimized (JSA 1997).

Since the 1997 publication, these conclusions have been shown to be accurate. Since 2004, there have been no further serious commercial outbreaks of any of the shrimp viruses in the U.S. (personal observation by author). There were also hearings in the U.S. Senate that explored the shrimp farming industry in 1996 and assessed the virus threat and how to stop it (U.S. Senate Hearing on "Marine Shrimp Farming and Aquaculture Research: hearing before a subcommittee of the Committee on Appropriations, U.S. Senate, 114th Congress, second session: special hearing, 1996").

Genetic selection for disease-resistant penaeids started in the U.S. in the late 1980s and early 1990s as a result of work by the USDA's Marine Shrimp Farming Program (Pruder 1992) (Ostrowski et al. 2005, 2006) (Moss 2007, 2008, 2009) (Moss et al. 2005a, 2005b, 2008a, 2008b, 2009). The technology and practices spread to other countries in the mid- to late 1990s, and that technology continues to spread (e.g., a recently announced sale of technology from the Oceanic Institute in Hawaii to China). For more information on High Health shrimp development, refer to Newman 2009.

Regular disease monitoring is carried out by the farms as well as the relevant state regulatory agencies. For example, in Texas, the regulatory agency responsible for monitoring and controlling exotic species (Texas Parks and Wildlife) sends a qualified biologist to each farm bimonthly to look for signs of shrimp diseases. If any visual evidence of disease is detected on or in the shrimp, the shrimp are sent to the disease testing laboratory in Arizona. If disease is found, appropriate measures are given by the regulatory agency. The only hatchery in Texas, KAPPA Aquafarm, is also required to preserve post-larval shrimp per OIE protocols monthly, and to send samples to the shrimp disease laboratory in Arizona for disease diagnostic testing. The protocols currently in place were developed by the USDA and modeled after the poultry and swine industries' successes with disease management. These protocols have been shown to control diseases in the U.S. shrimp aquaculture industry (Pruder 1992) (Ostrowski et al. 2005, 2006) (Moss 2007, 2008, 2009) (Moss et al. 2005a, 2005b, 2008a, 2008b, 2009).

The threat of spreading shrimp diseases to local species is minimized by the biosecurity measures practiced by farms and also by farms buying their seed animals from High Health, certified specific-pathogen-free sources. The biosecurity measures on U.S. shrimp farms are adopted from the OIE Aquatic Animal Health Code of Conduct and the disease testing used in the disease laboratories is outlined in the OIE Manual for Diagnostic Testing of Aquatic Animals. URL: http://www.oie.int/en/.

The OIE publishes an "Aquatic Animal Health Code" and a "Manual of Diagnostic Tests for Aquatic Animals," which the shrimp farm industries and pathology labs follow. Updated editions are published approximately every 3 years; http://www.oie.int/en/international-standard-setting/aquatic-manual/access-online/ [site accessed on 7/16/13]. There is also the "OIE Quality Standard and Guidelines for Veterinary Laboratories," which provides a specific interpretation of the generally stated requirements of the International Standards Organization (ISO)/IEC 17025 for veterinary laboratories.

The U.S. marine shrimp farming industry has not been troubled by shrimp viruses in recent years. But, there are more than 20 known viruses that infect shrimp, and 4 continue to pose a major threat to the world industry (infectious hypodermal and hematopoietic necrosis virus, IHHN; Taura syndrome virus, TSV; yellow head virus, YHV; and white spot syndrome virus, WSSV). In the Western Hemisphere, 9 of the 20 viruses have killed shrimp, and 5 are considered serious pathogens. In the Eastern Hemisphere, 12 viruses have been found, with 5 causing mass mortality.

More recently, another disease has caused mass mortality of shrimp in Asia: early mortality syndrome (EMS). This disease typically manifests in the first 10 to 40 days after stocking postlarvae in ponds, and was first reported in China in 2009. It then spread to Vietnam in 2010, to Malaysia in 2011, and to Thailand in 2012 (in 2013, it spread to Thailand's productive southern region). Global losses due to EMS are well in excess of USD 1 billion per year. Despite the four-year history of this disease, its cause has been obscure until recently. Initially, it was unclear whether an environmental toxin or an infectious agent caused the disease. At a panel discussion on EMS at a conference in Bangkok on October 31, 2012, experts such as Don Lightner and Timothy Flegel speculated that the elusive nature of the disease might be explained by a bacteriophage, which is a virus that can transfer lethal toxin genes to bacteria. Examples of diseases in which bacteriophages cause toxicity of bacteria are diphtheria and cholera in humans and *Vibrio harveyii* in shrimp.

A recent breakthrough by Lightner and his team at the University of Arizona not only confirms the cause as a pathogen—not an environmental toxin—but also provides an experimental model for identifying the infectious agent. This is expected to lead to rapid progress in developing diagnostic tools and to a better understanding of techniques for managing the disease. It is hoped that this breakthrough will help control this disease and mitigate the risks of an outbreak in the U.S. shrimp aquaculture industry through prevention and biosecurity practices.

Transmission of exotic pathogens can occur through a variety of means, including movement by humans, birds, and other animals, as well as through the shipment of infected frozen food products (Humphrey 1995). Several studies of the method of introduction of WSSV into Texas (after the initial 1995 outbreak) concluded that the introduction and spread of WSSV may be through the importation of frozen shrimp product (both as bait for sport fishers and as products available in markets for human consumption) (Lightner 1996) (Nunan et al. 1998).

Wastes from shrimp-processing plants pose another major potential disease exposure pathway to shrimp in the U.S. Foreign wild-shrimp harvesters may catch shrimp with diseases and ship them to the U.S. as a frozen product. Likewise, some foreign aquaculture operations harvest their ponds immediately upon finding disease and export the infected shrimp. Shrimp from foreign countries are repackaged at processing plants in the U.S., and the solid wastes, such as the carapace, were historically disposed of into local waters or landfills (Overstreet et al., 1997). This practice represents a significant biosecurity risk, and the dumping of shrimp heads offshore was stopped. But, processing wastes still continue to be dumped in landfills, where birds have access and transport the wastes some distances. Composting is a more secure biological solution for processing wastes, and some shrimp-processing facilities send their wastes for composting.

Although shrimp viruses do not affect humans who consume infected shrimp, a study of frozen imported shrimp sampled in 12 grocery stores in Arizona, California, and Texas found that 5 of the 12 samples of shrimp had either WSSV or YHV (Nunan, Poulos, and Lightner 1998). Freezing does not destroy the virus—in fact, freezing is the preferred method of virus preservation among pathologists. In laboratory experiments, infection and mortality occurred when frozen imported shrimp were fed to live shrimp. Polymerase chain reaction (PCR) tests confirmed that the viruses were present in the frozen supermarket shrimp (Nunan, Poulos, and Lightner 1998).

Despite significant advancements in the areas of shrimp disease management and mitigation, several recent developments have reduced the United States' capacity for further research. The U.S. Congress initiated the U.S. Marine Shrimp Farming Program, which resulted in valuable developments with Specific Pathogen Free (or High Health) *L. vannamei* and genetically improved animals (improved growth); however, funding for this program expired in 2011, ending studies. In addition , the Texas Veterinary Medical Diagnostic Center in College Station closed the APHIS-certified laboratory that worked with aquatic diseases in Texas. As a result, there are relatively few remaining laboratories in the U.S. that now work with shrimp diseases (labs exist in Arizona, Mississippi, and Florida).

Current production practices employ biosecurity and best management practices to mitigate disease outbreaks and do not increase the likelihood of pathogen amplification or transmission to natural populations. The final numerical score for Criterion 7—Disease is 8 out of 10.

Criterion 8: Source of Stock – independence from wild fisheries

Impact, unit of sustainability and principle

- *Impact: the removal of fish from wild populations for on-growing to harvest size in farms*
- *Sustainability unit: wild fish populations*
- *Principle: aquaculture operations use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture*

Criterion 8: Source of Stock

Source of stock parameters	Score	
C8 % of production from hatchery-raised broodstock, natural (passive) settlement, or sourced from sustainable fisheries	100	
C8 Source of stock Final Score	**10.00**	**GREEN**

Brief Summary

Current U.S. shrimp farming operations rely completely on hatchery-reared broodstock for juveniles. Thus, there is no dependence on wild stocks for seed, and the score for Criterion 8—Source of Stock is 10 out of 10.

Justification of Ranking

25 years ago, the original development of specific-pathogen-free (SPF) shrimp used wild shrimp stocks as the source. But, soon after the establishment of the SPF program, animals were selected from 44 different domestic families that produced desired traits; these animals were incorporated into the SPF program as genetically improved animals (USDA USMSFP). For all U.S. shrimp farming operations during the last 25 years, the source of broodstock has been from the USDA U.S. Marine Shrimp Farming Program's High Health shrimp stocks, which are held in quarantine in Hawaii. But, the U.S. Congress defunded the program in 2011 and, at about the same time, Shrimp Improvement Systems, Inc. (SIS, in Florida, is the largest shrimp hatchery in the U.S.) was purchased by CP-Indonesia. SIS provides most of the broodstock in the U.S. and their stocks originated from the USMSFP program. Today, broodstock still originate from SIS's High Health, genetically improved shrimp stocks, but the broodstock program was moved to Hawaii for better hurricane protection in 2014.

A significant step toward intensification of *L. vannamei* culture and domestication started in the 1980s and continued into the 1990s in the United States. In Hawaii, Dr. James Wyban (Wyban and Sweeney 1991) published an intensive culture manual and moved toward stock selection and specific-pathogen-free stocks. The USDA U.S. Marine Shrimp Farming Program started over 25 years ago and further developed the SPF concept, following the techniques used in the poultry and swine industries. Most other shrimp development programs around the world now follow similar procedures, and all have agreed to follow the OIE Aquatic Animal Code.

Wyban further developed High Health *P. monodon* with similar techniques as those used with *vannamei.* Once the steps to domestication (i.e., mass selection, family selection, walk-back selection, marker-assisted selection, or transgenics) are completed, there is no further reliance on the wild populations. The species is then considered domesticated, and generally more desirable for culture than wild shrimp. *L. vannamei* has been considered domesticated for the past 10 years. The process was described in a number of U.S. Marine Shrimp Farming Program publications and scientific articles (Lee 2005; Ostrowski et al. 2005, 2006; Pruder 1992; Moss 2007, 2008, 2009; Moss et al. 2005a, 2005b, 2008a, 2008b, 2009).

All farmed stock is considered completely independent of wild populations. Therefore, the final score for Criterion 8—Source of Stock is 10 out of 10.

Criterion 9X: Wildlife and predator mortalities

A measure of the effects of deliberate or accidental mortality on the populations of affected species of predators or other wildlife.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 9X Summary

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score	**–2.00**	**GREEN**
Critical?	NO	

Brief Summary

Best management practices and nonlethal methods are effective at deterring predation of farmed shrimp in the U.S., but wildlife mortalities are known to occur in exceptional cases. Precise data on numbers of mortalities are unavailable; however, no threatened or endangered species are affected, and the exceptional mortalities are not shown to have a population-level effect. The final numerical score for Exceptional Criterion 9X is –2 out of –10.

Justification of Ranking

Although U.S. shrimp aquaculture operations may attract or interact with predators or other wildlife, there do seem to be effective management and prevention measures in place that limit wildlife mortalities to exceptional cases. Common predators on shrimp farms include birds (waders, diving ducks, and cormorants), wild pigs, muskrats, beavers, otters, rattlesnakes, and alligators. Bird predation has the most significant economic impact on aquaculture operations, and the Southern Regional Aquaculture Center offers extension services for implementing nonlethal deterrents such as scaring devices as well as physical barriers (Littauer et al. 1997). Although exceptions may be granted, the Migratory Bird Treaty Act of the U.S. prohibits the killing of migratory bird species (16 U.S.C. 703), and more information can be found at URL: http://www.law.cornell.edu/uscode/text/16/703.

There is some difficulty in finding information about predator mortality (as noted in the low data score for this Criterion). For example, it is known that farms may apply to the U.S. Fish and Wildlife Service for permits to kill avian predators, but it is unknown how many birds are allowed to be killed on each permit. In general, farmers are not willing to discuss the measures taken or required to control birds and other wildlife, and information is not available in the scientific literature; however, in the author's experience, nonlethal methods are utilized much more often than lethal ones.

Air cannons and other noisemakers such as firecrackers, exploding rockets, or flare guns are initially effective, but birds become accustomed to these noises and the efficacy of these methods is quickly reduced. Monofilament plastic fishing line can be stretched across a pond to deter birds' flight; however, this method is not practical for large ponds.

Farm operators report mostly nuisance occurrence of predatory birds, but lethal action to remove predators has occurred in some exceptional cases. The U.S. Fish and Wildlife Service issues a bird control permit that allows the farmer to use lethal action on a very limited number of birds and other predatory species. The double-breasted cormorant is one such bird predator that can eat significant volumes of farmed shrimp (it has been reported to be able to eat its weight in shrimp each day). The seagull is more of a nuisance bird than a predator bird; seagulls commonly fly behind the feed blower and land in the water to consume shrimp feed. Farmers use a sinking feed for shrimp, which helps deter seagulls.

No threatened or endangered species prey on farmed shrimp, and the predators that do occur exhibit robust local populations. As shown, wildlife mortalities occur, but these mortalities are limited to exceptional cases, and regulatory oversight ensures that this lethal take does not significantly affect the wildlife or predator species' population size. Thus, the final numerical score for Exceptional Criterion 9X is –2 out of –10.

Criterion 10X: Escape of unintentionally introduced species

A measure of the escape risk (introduction to the wild) of alien species other than the principle farmed species unintentionally transported during live animal shipments.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score.

Criterion 10X Summary

Escape of unintentionally introduced species parameters	**Score**	
C10Xa International or trans-waterbody live animal shipments (%)	10.00	
C10Xb Biosecurity of source/destination	10.00	
C10X Escape of unintentionally introduced species Final Score	**0.00**	**GREEN**

Brief Summary

The biosecurity of both the source and destination facilities in U.S. shrimp farming is shown to be high. Therefore, the concern regarding the escape of intentionally introduced species (other than the farmed shrimp) is null. The final score for Exceptional Criterion 10X is 0 out of –10.

Justification of Ranking

U.S. shrimp farms utilize only domestically raised postlarvae, or they must be from a hatchery that has a health certification and is classified as disease-free. International hatcheries must also have their shrimp tested in the same manner as U.S. hatcheries, and at the same shrimp disease laboratory in Tucson, Arizona. In the last 33 years of commercial shrimp farming, no shrimp were released accidentally during shipping from the hatchery to the grow-out destination. Because OIE biosecurity measures are strictly employed, so far there have been no impacts surrounding international or trans-waterbody live shrimp shipments.

A hurricane or flood event has not caused an accidental release of exotic shrimp on the mainland U.S. or Hawaii since the first shrimp farm was built in Texas in 1980. Contingency plans are required and in place at all coastal shrimp farms. Pond dikes are required to be 1 foot above the 100-year floodplain, which in Texas results in most pond dikes being built 15 feet above sea level. Accidental releases were found at an Arroyo City shrimp farm in the 1990s by regulatory agencies; as a result, Texas Parks and Wildlife Dept. manually closed the farm discharge and later implemented strong regulations on exotic releases on the coast, which was effective at stopping the releases.

Because both the source and destination biosecurity is high, the final score for Exceptional Criterion 10X—Escape of unintentionally introduced species is 0 out of –10.

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Appendix 1: Selected examples of existing U.S. regulations relevant to shrimp farms

Shrimp Aquaculture Permits in the U.S., State by State

Shrimp aquaculture is regulated differently in each state, but each state requires a minimum of three to four permits to develop a shrimp farm: 1) Coastal Use Permit; 2) Rivers and Harbors Act Section 10 permit; 3) Water Quality Certifications or discharge permit; and 4) a general license to operate. How these permits and leases are approved and issued differs from state to state. Different state agencies may take the lead during the permitting process, and the number of agencies involved in the review process varies. The process is streamlined in some states by joint application. Most states require more than the four previously mentioned permits, such as an Aquaculture Certification in Florida and permits required to handle certain (exotic) organisms. In addition to the aquaculture certification, a Section 10 permit is required to install any equipment and/or obstructions to navigation (33 U.S.C. §403). The United States Army Corps of Engineers (USACE) is responsible for issuing these permits, regardless of whether the project is in state or federal waters. Water certifications and National Pollutant Discharge Elimination System (NPDES) permits are required, and these permits are handled by the FDEP (33 U.S.C. §1344).

Alabama

In Alabama, there is no aquaculture certification program or aquaculture permit program. Aquaculture is regulated by the Alabama Department of Environmental Management (ADEM). Together with the U.S. Army Corp of Engineers, the ADEM reviews proposed projects and addresses the necessary permits required (Wallace and Fitzgibbons 1997). The ADEM also issues the coastal use permits. In addition , in Alabama, the Section 10 permit application is submitted separately from the coastal use permit, and the USACE Mobile District has a joint Section 10 and Section 404 permit application. Shrimp farms must abide by U.S. EPA and ADEM regulations for discharge. All the farms in Alabama are located inland from the coast.

Florida

In Florida, neither agricultural nor aquaculture operations are required to obtain county permits. But, Florida law (see Florida Statutes Chapter 570) requires that shrimp farms and other aquaculture operations register with the Florida Department of Agriculture and Consumer Affairs. The Certificate of Registration costs $50 and requires that the farmer agree to follow the Department's "best management practices" (BMPs). If the farmer follows the BMPs, the Department of Environmental Protection is prohibited from charging the farmer with environmental violations (such as the discharge of sewage or effluent) into surface waters.

The implementing rules (see Florida Administrative Code Chapter 5L-3) do not require aquafarmers "to follow the effluent treatment BMPs" if they use "recirculation systems" or "do not discharge to waters of the state"—in those cases, they are labeled as having a "minimal impact on the surrounding environment." Even if they do not meet those exceptions, the BMPs for effluent treatment require only a retention, an evaporation, or a percolation pond or a vegetated filter strip. A later Florida Aquaculture policy act declared aquaculture a form of agriculture, and re-affirmed that the Department of Agriculture and Consumer Services is responsible for permitting aquaculture and required to coordinate permits with other state agencies during the permitting process (Fla. Stat. Ann. § 597.002). Florida has a state aquaculture plan that requires all aquaculture producers to become permitted and provides aid in applying for permits to those within the industry (Fla. Stat. Ann. §591.0023, §597.004).

Louisiana

Mariculture is permitted by the Louisiana Department of Wildlife and Fisheries, but permits are only issued for mariculture on private lands and private water-bottoms (La. R.S. §56:579.1). Few entities have applied for permits, and all who have applied have been denied or their applications were rescinded. At the time of this report, there were no shrimp farms in Louisiana.

Mississippi

To establish a shrimp farm, additional permits are needed above and beyond receiving authorization from the county port authority to place an operation in its jurisdictional waters. This will include the Mississippi Coastal Zone Wetlands (MCZW) permit, issued by the Mississippi Department of Marine Resources (MDMR) in cooperation with the USACE. The MCZW permit is a joint permit that covers the coastal use permit, the Section 10 permit, the state water permit, the §401 water quality certification, and any §404 permitting needs. Under MDMR Ordinance 13.001, MDMR prohibits the discharge of "any waste material including, but not limited to, solids, debris, sanitary and kitchen wastes, oils and grease, the excrement of the cultured species, and commercially prepared feeds fed to them" (MDMR ordinance initiated in 2000). Under the same Ordinance 13.001, aquaculturists are required to perform a pre-operation environmental survey, as well as develop and implement a marine aquaculture environmental monitoring program consisting of four principal elements: a hydrographic survey, sediment chemistry, water quality, and a benthic survey.

Texas

Texas mariculture is regulated mainly by the Texas Department of Agriculture (TDA), Texas Parks and Wildlife Department (TPWD), and the Texas Commission on Environmental Quality (TCEQ). A memoranda of agreement, which requires all three state agencies to work together in permitting aquaculture, went into effect in 1999 (Treece 2005). Before any aquaculture operation can legally begin operation, a discharge permit or exemption from TCEQ must be obtained (Texas Water Code §11), a permit is required from the TDA (Texas Agriculture Code §134.011) and, if working with exotics (such as *L. vannamei*), a permit must be obtained from TPWD (Texas Agriculture Code § 134.020). The U.S. Army Corp. of Engineers reviews all permits, and EPA has an added layer of permits concerning aquaculture discharges. EPA rules take precedence over state (TCEQ) rules, unless the state's rules and regulations are more stringent. EPA's NPDES permits are required under FDEP (33 U.S.C. §1344) and the TCEQ also requires a similar TPDES. Each shrimp farm on the Texas coast is individually permitted with site-specific requirements for discharges. Discharge waters must be equal to or better than receiving waters.

Selected List of Key Shrimp Aquaculture Regulations in U.S., State by State

- Ala. Code. §11-23-1. Title 11. Counties and municipal corporations. Subtitle 1. Provisions Applicable to Counties Only. Chapter 23: Industrial Parks. Establishment authorized.
- Ala. Constitution Amendment 543. Natural lands and waters; preservation, etc.
- Fla. Stat. Ann. § 253.67-253.75. Title 18. Public Lands and Property. Chapter 253 State Lands.
- Fla. Stat. Ann. §253.68. Title 18. Public Lands and Property. Chapter 253 State Lands. Authority to lease or use submerged lands and water column for aquaculture activities.
- Fla. Stat. Ann. §253.69. Title 18. Public Lands and Property. Chapter 253 State Lands. Application to lease submerged land and water column.
- Fla. Stat. Ann. § 597.002. Title 35. Agriculture, Horticulture, and Animal Industry. Chapter 597: Aquaculture. Legislative declaration of public policy respecting aquaculture.
- Fla. Stat. Ann. § 597.004. Title 35. Agriculture, Horticulture, and Animal Industry. Chapter 597: Aquaculture. Aquaculture certificate of registration.
- Miss. Code § 59-9-5. Title 59. Ports, Harbors, Landings, and Watercraft. Chapter 9: County Port Authority or Development Commission. Definitions.
- Miss. Code §59-9-23. Title 59. Ports, Harbors, Landings, and Watercraft. Chapter 9: County Port Authority or Development Commission. Establishment and development of industrial parks.
- Miss. Code § 79-22-25. Title 79. Corporations, Associations, and Partnerships. Chapter 22: Mississippi Aquaculture Act of 1988. Management plan to be developed; Aquatic Ventures Center.
- Miss. Dept. of Marine Resources (DMR). 2000. Ordinance 13.001. An ordinance to regulate aquaculture in the marine environment. http://www.dmr.state.ms.us/ordinances/13001.pdf.
- Tex. Agriculture Code §134.011. Title 6. Production, Processing, and Sale of Animal Products. Subtitle A. Bees and Non-livestock Animal Industry. Chapter 134: Regulation of Aquaculture. Subchapter B: Aquaculture License. Licensing
- Tex. Agriculture Code §134.013 Title 6. Production, Processing, and Sale of Animal Products. Subtitle A. Bees and Non-livestock Animal Industry. Chapter 134: Regulation of

Aquaculture. Subchapter B: Aquaculture License. Additional requirements for shrimp production within the Coastal Zone.

- Tex. Natural Resources Code § 33.103(1). Title 2. Public Domain. Subtitle C. Chapter 33: Management of Coastal Public Lands. Subchapter D: Rights in Coastal Public Land. Leases for public purpose.
- Tex. Natural Resources Code § 33.105. Title 2. Public Domain. Subtitle C. Chapter 33: Management of Coastal Public Lands. Subchapter D: Rights in Coastal Public Land. Person whom land may be leased.
- Tex. Water Code §11 et seq. et seq. Title 2. Water Administration. Subtitle B. Water Rights. Chapter 11: Water Rights. Subchapter B: Rights in State Waters.
- U.S. Code Title 33 § 403. Navigation and Navigable Waterways. Chapter 9: Protection of Navigable Waters and of Harbor and River Improvements Generally in General. Obstruction of navigable waters generally; wharves; piers, etc.; excavations and filling.
- U.S. Code Title 33 § 1344. Navigation and Navigable Waterways. Chapter 26: Water Pollution Prevention and Control Permits. Permits for dredge or fill material.

Appendix 2: Data points and all scoring calculations

This is a condensed version of the criteria and scoring sheet to provide access to all data points and calculations. See the Seafood Watch Aquaculture Criteria document for a full explanation of the criteria, calculations and scores. Yellow cells represent data entry points.

Criterion 1: Data quality and availability

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	*Yes*	10	10
Effluent	Yes	7.5	7.5
Locations/habitats	Yes	10	10
Predators and wildlife	Yes	2.5	2.5
Chemical use	Yes	5	5
Feed	Yes	7.5	7.5
Escapes, animal movements	Yes	10	10
Disease	Yes	10	10
Source of stock	Yes	10	10
Other – (e.g. GHG emissions)	No	Not relevant	n/a
Total			**72.5**

C1 Data Final Score	8.055555556	GREEN

Criterion 2: Effluents

Effluent Rapid Assessment

C2 Effluent Final Score	**8.00**	**GREEN**

Criterion 3: Habitat

3.1. Habitat conversion and function

F3.1 Score	**9**

3.2 Habitat and farm siting management effectiveness (appropriate to the scale of the industry)

Factor 3.2a - Regulatory or management effectiveness

Question	Scoring	Score
1 - Is the farm location, siting and/or licensing process based on ecological principles, including an EIAs requirement for new sites?	Yes	1

2 - Is the industry’s total size and concentration based on its cumulative impacts and the maintenance of ecosystem function?	Yes	1
3 – Is the industry’s ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services?	Yes	1
4 - Are high-value habitats being avoided for aquaculture siting? (i.e., avoidance of areas critical to vulnerable wild populations, effective zoning, or compliance with international agreements such as the Ramsar treaty)	Yes	1
5 - Do control measures include requirements for the restoration of important or critical habitats or ecosystem services?	Yes	1
		5

Factor 3.2b - Siting regulatory or management enforcement

Question	Scoring	Score
1 - Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry?	Yes	1
2 - Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures?	Yes	1
3 - Does the farm siting or permitting process take account of other farms and their cumulative impacts?	Yes	1
4 - Is the enforcement process transparent - e.g. public availability of farm locations and sizes, EIA reports, zoning plans, etc.?	Mostly	0.75
5 - Is there evidence that the restrictions or limits defined in the control measures are being achieved?	Yes	1
		4.75

F3.2 Score (2.2a*2.2b/2.5)	**9.50**	
C3 Habitat Final Score	**9.17**	**GREEN**
	Critical?	NO

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	Score	
C4 Chemical Use Score	**6.00**	
C4 Chemical Use Final Score	**6.00**	**YELLOW**
Critical?	NO	

Criterion 5: Feed

5.1. Wild Fish Use

Factor 5.1a - Fish In: Fish Out (FIFO)

Fishmeal inclusion level (%)	25
Fishmeal from byproducts (%)	0

% FM	25
Fish oil inclusion level (%)	6
Fish oil from byproducts (%)	0
% FO	6
Fishmeal yield (%)	22.5
Fish oil yield (%)	5
eFCR	1.8
FIFO fishmeal	2.00
FIFO fish oil	2.16
Greater of the 2 FIFO scores	2.16
FIFO Score	**4.60**

Factor 5.1b - Sustainability of the Source of Wild Fish (SSWF)

SSWF	
SSWF Factor	–0.86

F5.1 Wild Fish Use Score	**3.74**

5.2. Net protein Gain or Loss

Protein INPUTS	
Protein content of feed	35
eFCR	1.8
Feed protein from NON-EDIBLE sources (%)	26
Feed protein from EDIBLE CROP sources (%)	37
Protein OUTPUTS	
Protein content of whole harvested fish (%)	17.8
Edible yield of harvested fish (%)	62
Non-edible byproducts from harvested fish used for other food production	50
Protein IN	39.95
Protein OUT	14.418
Net protein gain or loss (%)	–63.9129
Critical?	NO
F5.2 Net protein Score	**3.00**

5.3. Feed Footprint

5.3a Ocean area of primary productivity appropriated by feed ingredients per ton of farmed seafood

Inclusion level of aquatic feed ingredients (%)	31
eFCR	1.8
Average Primary Productivity (C) required for aquatic feed ingredients (ton C/ton fish)	*69.7*
Average ocean productivity for continental shelf areas (ton C/ha)	*2.68*
Ocean area appropriated (ha/ton fish)	14.51

5.3b Land area appropriated by feed ingredients per ton of production

Inclusion level of crop feed ingredients (%)	33.5
Inclusion level of land animal products (%)	0
Conversion ratio of crop ingredients to land animal products	*2.88*
eFCR	1.8
Average yield of major feed ingredient crops (t/ha)	*2.64*
Land area appropriated (ha per ton of fish)	0.23

Value (Ocean + Land Area)	**14.74**	
F5.3 Feed Footprint Score	**5.00**	
C5 Feed Final Score	**3.87**	**YELLOW**
	Critical?	**NO**

Criterion 6: Escapes

6.1a. Escape Risk

Escape Risk	**6**

Recapture & Mortality Score (RMS)	
Estimated % recapture rate or direct mortality at the escape site	90
Recapture & Mortality Score	0.9
Factor 6.1a Escape Risk Score	**9.6**

6.1b. Invasiveness

Part A – Native species

Score	0

Part B – Non-Native species

Score	**2**

Part C – Native and Non-native species

Question	Score
Do escapees compete with wild native populations for food or habitat?	Yes
Do escapees act as additional predation pressure on wild native populations?	Yes
Do escapees compete with wild native populations for breeding partners or disturb breed	No
Do escapees modify habitats to the detriment of other species (e.g. by feeding, foraging, s	Yes
Do escapees have some other impact on other native species or habitats?	No
	2

F 6.1b Score	**4**

Final C6 Score	**6.00**	**YELLOW**
	Critical?	**NO**

Criterion 7: Diseases

Pathogen and parasite parameters	Score
C7 Biosecurity	8.00
C7 Disease; pathogen and parasite Final Score	**8.00**
Critical?	NO

Criterion 8: Source of Stock

Source of stock parameters	Score	
C8 % of production from hatchery-raised broodstock, natural (passive) settlement, or sourced from sustainable fisheries	100	
C8 Source of stock Final Score	**10**	**GREEN**

C9X: Wildlife mortalities

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score	**–2.00**	**GREEN**
Critical?	NO	

C10X: Escape of unintentionally introduced species

Escape of unintentionally introduced species parameters	Score	
C10Xa International or trans-waterbody live animal shipments (%)	10.00	
C10Xb Biosecurity of source/destination	0.00	
C10X Escape of unintentionally introduced species Final Score	**0.00**	**GREEN**

Appendix 3: Shrimp Certification Programs

World Shrimp Certification Programs

1. Alter-Trade Japan (ATJ) is a Japanese company involved in fair trade with several commodities including bananas, coffee, and shrimp. The shrimp is labeled by ATJ as "eco-shrimps" based on their own standards. Since 2000, ATJ has worked with Naturland to develop a certified organic shrimp product using Naturland organic standards. The two groups merged in 2003 to form ATJNA to further work toward better management of production, processing and organic certification of shrimp.

2. Aquaculture Certification Council, Inc. (ACC) is a nongovernmental, nonprofit, nonmember public benefit corporation established to certify social, environmental, and food safety standards at aquaculture facilities throughout the world. It is a certification of the process or how the shrimp were produced and not a quality certification. The ACC builds on elements of the voluntary responsible aquaculture program by Global Aquaculture Alliance (GAA) in a process certification system that combines site inspections and effluent sampling with testing and verification, sanitary controls, therapeutic controls, and traceability. Guidelines for best aquaculture practices (BAP) standards can be found on the ACC URL: www.aquaculturecertification.org.

BEST AQUACULTURE PRACTICES CERTIFIED®
☑ Processor ☑ Farm
Cert. No. XXXXXX
responsibleseafood.org
Wholesome Seafood.
Responsibly Produced.

Optional Text (Processor/Farm)
Best Aquaculture Practices certification
means this shrimp was farmed and processed
in an environmentally and socially responsible
manner. Visit www.responsibleseafood.org
for program details.

BEST AQUACULTURE PRACTICES CERTIFIED®
☑ Processor ☑ Farm
Cert. No. XXXXXX
responsibleseafood.org
Wholesome Seafood.
Responsibly Produced.

The BAP mark on retail packaging means the shrimp came from a BAP-certified facility. Visit the ACC website for more detail.

3. Carrefour is the first retailer in Europe and second largest in the world. They are involved in fair trade of Carrefour Quality Line shrimp produced in Brazil and Madagascar.

4. Environmental Justice Foundation (EJF) has prepared a protocol for sustainable shrimp aquaculture as part of their campaign to encourage retailers "to only sell shrimp proven to be produced without harming natural environments, local communities or human rights."

5. International Standards Organization (ISO) 14001 is the standard for environmental management, not for a product, but for minimizing harmful effects on the environment caused by shrimp farming. More information can be found at ISO 14001 website. ISO 14001 is

protected by copyright and is not free.

6. Naturland has developed standards on several aquaculture commodities and issued its standards on organic shrimp production in 1999. “Naturland Standards for organic Aquaculture” includes a specific section for pond culture of the Pacific white shrimp.

7. Safe Quality Food (SQF) is a program under the Food Marketing Institute. The certification system SQF1000 is for production and SQF2000 is for processing plants. SQF covers a global range volume of shrimp products. Thus far, processors are certified under the SQF1000 program, but not producers.

8. Shrimp Seal of Quality (SSoQ) of Bangladesh was established to certify farmed shrimp based on their own Code of Conduct. These certification standards describe the requirements that must be met by shrimp operators (hatcheries, farmers, transporters, and processors) in order to receive SSoQ certification. SSoQ is a voluntary process certification and certifies that the operator is deemed to have met the minimum requirements in the areas of food safety, quality assurance, traceability, environmental sustainability, labor practices and social responsibility.

9. The Soil Association has prepared general standards for organic aquaculture, mainly focused on salmon, trout, and shrimp farming.

10. Thai Quality Shrimp (Thailand)—The Department of Fisheries of Thailand prepared the certification system for shrimp aquaculture, with the intention of producing shrimp under their Codes of Conduct. The certification covers hatchery, farm, processing plant, and distributor, and promotes the products under the label “Thai Quality Shrimp.”

Other Closely Related Aquaculture Certifications

1. BioGro New Zealand has developed standards for organic fish farming including fish, shellfish, and crustaceans, and the processing of those products.

2. Bio Suisse is an umbrella organization for organic agriculture in Switzerland. Bio Suisse is certifying farmed fish such as carp, char, and perch. The standards only apply to inland and freshwater farming and are designed for the Swiss market.

3. Fundacion Chile in cooperation with Chilean salmon farming companies prepared an Environmental Code of Practice that is intended to serve as the basis for a certification system for Chilean salmon farming. Their code of practice is translated into the English, Norwegian, Spanish, and German languages.

4. International Federation of Organic Agriculture Movements (IFOAM) is a global umbrella body for organic food and farming. IFOAM has drawn up "Basic Standards for Organic Aquaculture."

5. The U.S. Department of Agriculture (USDA) has been working on standards for organic aquaculture. They established the National Organic Standards Board and have been working

toward setting standards for aquatic animal culture. URL:
http://www.ams.usda.gov/nosb/index.htm

There are presently some quite large seafood buyers in the U.S. (Dardin Seafoods—Red Lobster, Walmart/Sam's Club) that require their seafood suppliers to have such certifications. Others will follow. Despite these positive signs, there is no evidence that U.S. consumers will buy domestic products over foreign, especially when given the choice and when they find a superior quality product that is safe and less expensive. Seafood imports are at a historic high level and, ironically, 40%–50% are estimated to be farmed products. Therefore, the long-term outlook for the U.S. producer continues to be head-to-head competition with overseas producers. Without U.S. government regulation, foreign competition—particularly from developing countries—will continue to offer low-priced commodities in the marketplace. This is because those nations have their own goals—to increase aquaculture production in coming years—and they have justified loans from international development banks on the lucrative seafood markets in Europe, Japan, and the United States. In addition , they have plans to repay their loans through the sale of high-value products made profitable by low labor and operating costs, and a greater amount of processing to obtain the value-added benefits. Provided that their aquaculture products meet the higher standards of human health and safety now imposed by most of the world on all food products, seafood producers in the U.S. will always face competition for market share.

Appendix 4: Interim Update (2022)

An Interim Update of this assessment was conducted in July 2022 in the most-up-to-date Seafood Watch Aquaculture Standard Version 4.0. Interim Updates focus on an assessment's limiting (i.e., Critical or Red) criteria (inclusive of a review of the availability and quality of data relevant to those criteria), so this review updates Criterion—5 Feed while also updating the Scope. No information was found or received that would suggest the final rating is no longer accurate. No edits were made to the text of the report (except an update note in the Executive Summary and all updated criteria). The following text summarizes the findings of the review.

Interim Update Summary

Results of the interim update support the findings of the previous assessment, and the Overall Recommendation for shrimp (*L. vannamei*) grown in ponds in the United States remains Best Choice with a Green rating. The recommendation and rating are a result of reviewing the limiting criterion, Criterion 5—Feed. For Factor 5.1a, the Feed Fish Efficiency Ratio (FFER) for fish meal is low, 0.599, and combines with the weighted average source fishery sustainability score for Factor 5.1b, 7 out of 10, for a final Wild Fish Use score of 7.35 out of 10 for Factor 5.1. The net protein loss for Factor 5.2 is moderate to high, –63.67%, and scores 3 out of 10. Factor 5.3—Feed footprint is scored 6 out of 10 due to a moderate feed footprint of 15.95 kg CO_2-eq per kg of farmed shrimp protein. Altogether Factor 5.1, 7.35 out of 10, Factor 5.2, 3 out of 10, and Factor 5.3, 6 out of 10, combine for a final score of 5.93 out of 10, which results in a Yellow rating for Criterion 5—Feed.

Also included in the following section is an update of the Scope of the report.

Scope of the Analysis and Ensuing Recommendation

Species: Whiteleg shrimp (*Litopenaeus vannamei*)
Geographic coverage: United States of America
Production Method: Ponds, intensive and semi-intensive

Species Overview

Litopenaeus vannamei lives in tropical marine habitats and is native to the Eastern Pacific coast from Sonora, Mexico in the north to Tumbes in Peru in the south. Thus, it is not native to any waters of the United States. As for all Penaeid species, adults live and spawn in the open ocean, while postlarvae (PL) migrate inshore to spend their juvenile, adolescent, and sub-adult stages in coastal estuaries, lagoons, or mangrove areas (FAO 2009).

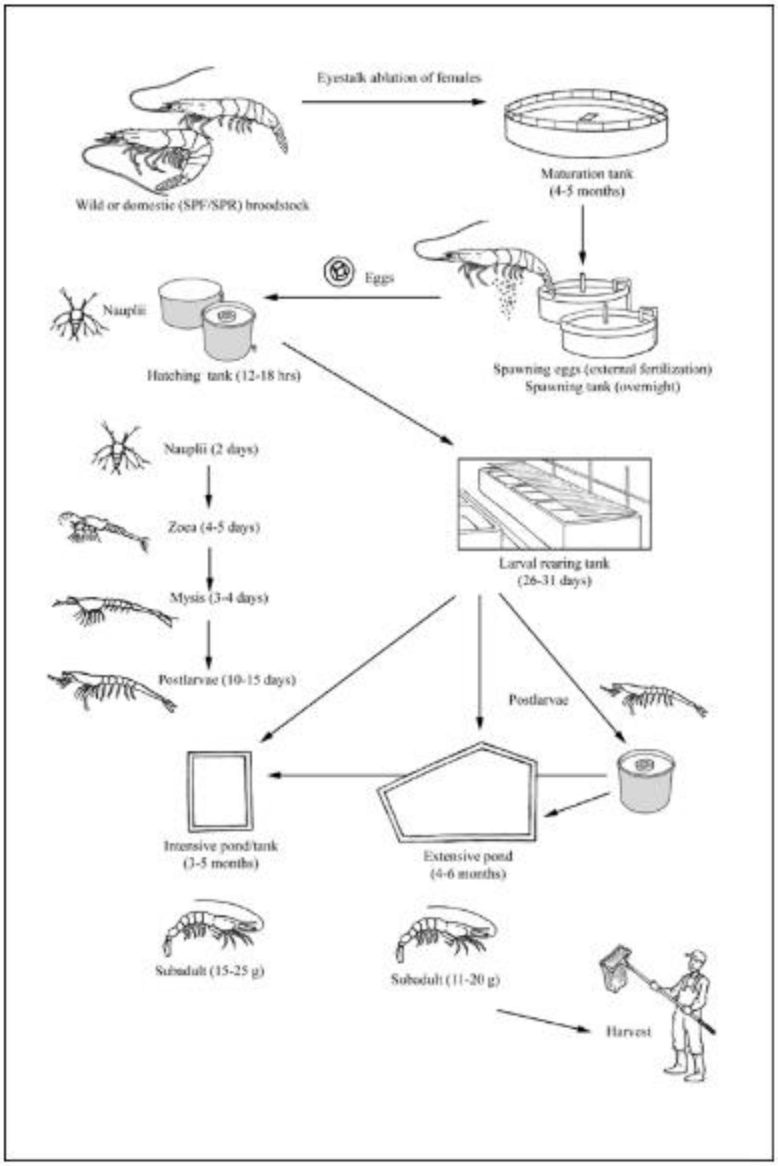
Production Systems

In the United States, whiteleg shrimp (*Litopenaeus vannamei*) is the only shrimp species grown for food consumption (FAO, 2018). Aquaculture production systems utilized to grow whiteleg shrimp in the United States include semi-intensive ponds, intensive ponds, intensive recirculating aquaculture systems, and indoor raceway production. It does not appear that indoor raceway production is significant. For instance, out of the 1,125 metric tons (henceforth, mt) produced in Texas in 2021, only about 1 mt was not produced in ponds (pers. comm., Granvil Treece, 2022). Additional and more definitive statistics were unable to be found in the literature. The production system that produces the most whiteleg shrimp by volume in the United States is intensive ponds that employ water reuse methods before discharge, followed by semi-intensive ponds that employ zero water exchange or recirculation methods (pers. comm., Granvil Treece, 2022). But, the industry trend is toward the adoption of indoor RAS systems (pers. comm., Granvil Treece, 2022). For example, American Mariculture and Homegrown Shrimp in Florida and Global Blue Technologies in Texas have all recently joined the industry with RAS systems.

As an approximate guide (FAO, 2009), intensive ponds are commonly located in nontidal areas and are increasingly located far from the ocean in cheaper and low salinity areas. Although intensive pond sizes commonly range from 0.1 to 1.0 hectares (ha), ponds in the U.S. have been reported to be larger (≈2 ha). Stocking densities for intensive ponds range from 60 to 300 postlarvae (PL)/m^2 and are supplemented with formulated diets 4 or 5 times per day. Production yields in intensive ponds range from 7 to 35,000 kg/ha/crop, with roughly 2 or 3 crops per year, depending on the climate. Semi-intensive ponds of typically 1 to 5 ha are stocked with hatchery-produced seeds at 10 to 40 PL/m^2. The shrimp feed on natural foods enhanced by pond fertilization, supplemented by formulated diets two or three times daily. Production yields in semi-intensive ponds range from 500 to 2,000 kg/ha/crop, with roughly 2 crops per year, depending on the climate.

Shrimp ponds are constructed as levee-type ponds in the United States. Levee ponds are constructed in flat areas with embankments for a total depth of about 1.5 meters (5 feet) (Avery, 2010) (Hicks and Pierce, 2014). Generally, brackish water or seawater is pumped into ponds and discharged periodically (SFW, 2014).

Shrimp farming consists of three stages: hatchery, nursery, and grow-out. Shrimp hatcheries raise broodstocks that may be genetically selected and bred for fast growth and specific-pathogen-free and/or -resistant stocks (Whetstone et al., 2002). Each spawning whiteleg female can produce between 150,000 and 200,000 eggs per batch, which catalyzes fertilization and, subsequently, the beginning larval planktonic stages (nauplii, zoea, and mysis). After the larval stage, postlarvae are transferred to nurseries or grow-out facilities, depending on the operation. A single shrimp farm may include all these operations or specialize in a particular phase, because each stage requires different methods and care. Shrimp aquaculture farms in the United States typically purchase postlarvae (PLs) from external hatcheries and stock into grow-out ponds to be later harvested, but there are some shrimp farms in the United States that have vertically integrated their production cycles and are able to cultivate their own broodstocks that supply their postlarvae needs, which are eventually stocked into in-house grow-out ponds. In recent years, the availability of postlarvae has been an increasing burden for U.S. farmers, because hatcheries prioritize exporting PLs over the limited domestic demand (pers. comm., Granvil Treece, 2020). The entire production cycle for whiteleg shrimp is described in Figure 6.



Production cycle of Penaeus vannamei

Figure 6: Production cycle of whiteleg shrimp (*L. vannamei*). Source: (FAO, 2009).

Given the current data available (detailed below), this assessment will evaluate all shrimp production from the United States at the grow-out stage of semi-intensive and intensive pond production systems.

Industry Statistics

<u>Background</u>

The United States began breeding whiteleg shrimp for farming production in 1973, which helped to support the development of aquaculture in Central and South America. By the early 1980s, Hawaii and parts of the mainland United States began farming whiteleg shrimp, but at low production volumes (FAO, 2009).

According to the Food and Agriculture Organization (2022), whiteleg shrimp farming production in the United States was first reported in 1984 and the industry has continued to develop, with production reaching a maximum in the year 2003 when 6,069 metric tons (henceforth, mt) of shrimp was harvested (Figure 7) (FAO, 2022). But, production sharply declined after 2003 and harvest volumes steadied from 2008 to 2019 (the last reported date for U.S. whiteleg shrimp production from the FAO was 2019) at 2,035 mt of harvested whiteleg shrimp.

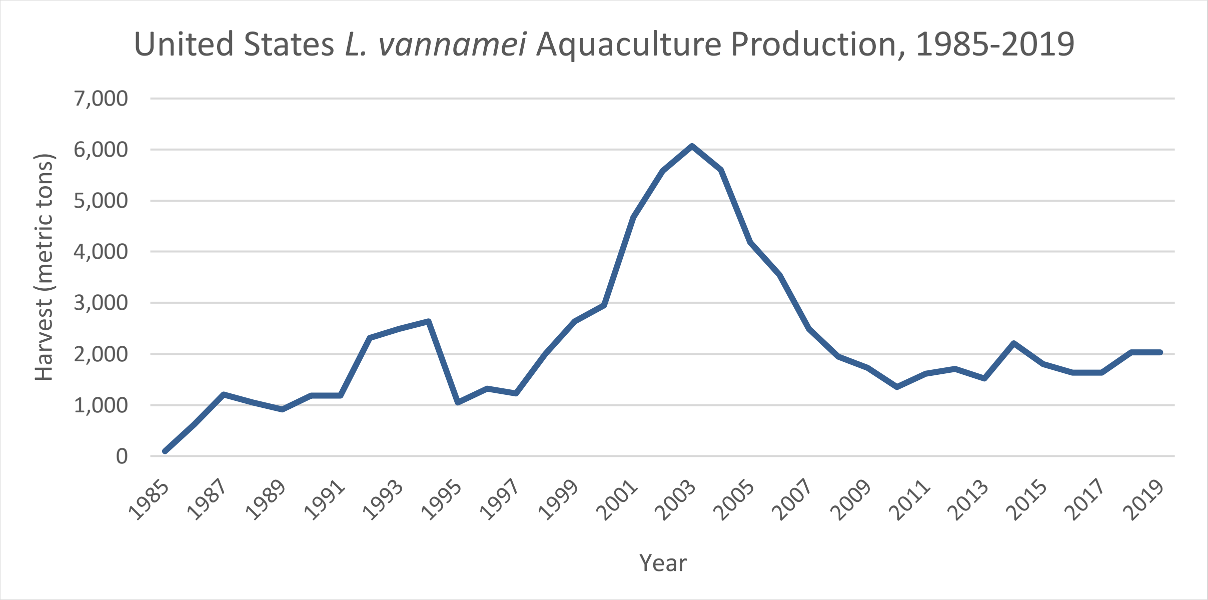


Figure 7: U.S. whiteleg shrimp—annual production (mt) from Food and Agriculture Organization, Global Aquaculture Production Quantity (February 2022)

Current U.S. shrimp farming metrics and industry insights were made available from the United States Department of Agriculture (USDA) 2018 Aquaculture Census. This census identified 31 farms actively producing shrimp for food in the United States, with total production of 4.4 million pounds (1,995 mt) of harvested whiteleg shrimp in 2018. Other operations include 5 farms operating solely as broodstock operations and 3 farms producing larvae and seed, for a total of 39 active shrimp farming operations in the United States (Table 5). According to the census, there are 13 states participating in shrimp aquaculture activities (see Table 5), but the census data do not make clear how much of this production occurs from each state and which production systems are utilized.

Table 5: U.S. shrimp farming operations in 2018.
Source: USDA 2018 Census of Aquaculture.

State	Number of Shrimp Operations
Florida	11
Hawaii	10
Texas	4
Iowa	2

Kentucky	2
Missouri	2
New Hampshire	2
Colorado	1
Idaho	1
Minnesota	1
Nebraska	1
Ohio	1
Alabama	1
TOTAL	**39**

A review of literature and personal communications with industry experts revealed that Texas, Hawaii, Florida, and Alabama all have commercially operating semi-intensive and intensive shrimp ponds. The production from other states listed in Table 5 are likely recirculating aquaculture systems (pers. comm., Mark Godwin, Gulf American Shrimp LLC, 2019; Luke Roy, Auburn University, 2019; Matt Smith, Ohio State University, 2019; Liz Akina, Hawaii Dept. of Agriculture Aquaculture and Livestock Support Services, 2019; and Treece and Associates, 2019). Although there are two farms producing shrimp for food in Hawaii, only one of them produces significant volumes, so it is the only one included in Table 6 (pers. comm. Todd Low, Hawaii Dept. of Agriculture, June 2022). The rest of the shrimp farms in Hawaii are focused on broodstock production. Further details, such as the number of grow out ponds, tons harvests, percentage of total pond production and hectares for each state were gathered through personal communications with industry stakeholders (Table 6).

Table 6: U.S. shrimp grow-out pond production in 2020 (pers. comm., Todd Sink, Granvil Treece, Todd Low, and Davis Allen 2022).

State	Number of Grow-out Operations	Tons Harvested (mt/yr)	% of Total Pond Production	Hectares
Texas	2	1,654.48	70.09	450
Hawaii	2	272.73	11.55	136*
Florida	3	363.64	15.41	182*
Alabama	1	69.55	2.95	28
Total	**8**	**2,360.39**	**100%**	**796**

* Estimated hectares calculated by dividing the given harvest (mt) per year by a semi-intensive yield of 2 mt/ha.

Therefore, the scope of this interim report evaluates U.S. pond (e.g., intensive and semi-intensive) production systems of whiteleg shrimp, while recirculating aquaculture systems production is covered by the *Seafood Watch Global Recirculating Aquaculture Systems report, 2020*.

U.S. Shrimp Export Market

Because farmed U.S. shrimp production is sold to domestic markets (pers. comm., Treece and Associates, 2020), the export market economic value, export products, and export markets are assumed to be entirely representative of the U.S. shrimp fishery, so they are excluded from this report.

U.S. Shrimp Import Market

The top six countries supplying shrimp to the United States include (in order of total supply in 2021): India, Ecuador, Indonesia, Vietnam, Thailand, and China (Figure 8). In recent years (after 2019), market share has increased for India, Ecuador, Indonesia, and Vietnam, while market share has decreased for Thailand and China (NOAA Fisheries, 2022).

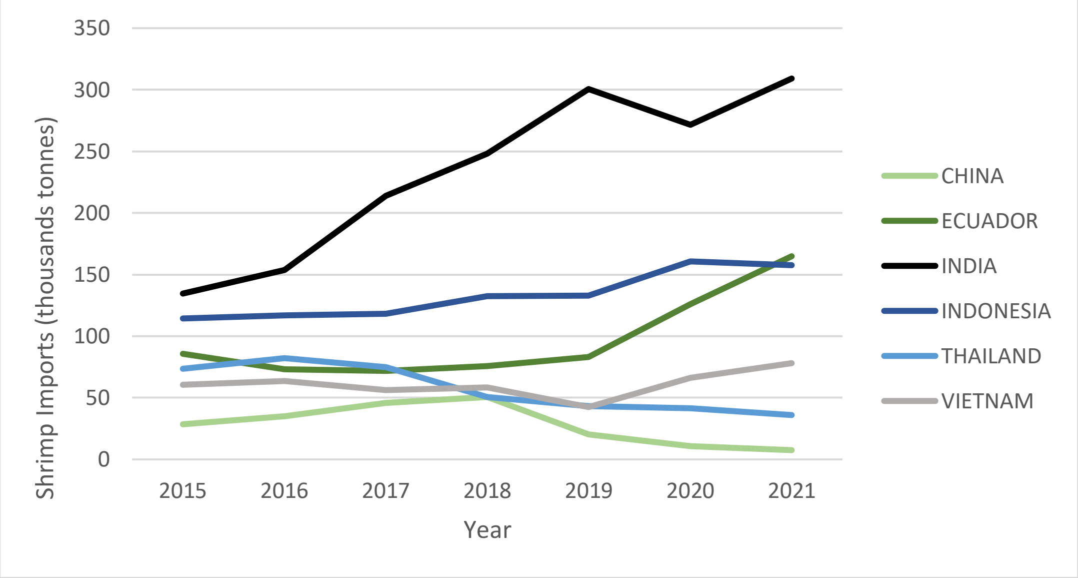


Figure 8: Top six countries the United States imports shrimp from, 2015 to 2021. Source: (NMFS, 2022)

In 2021, the United States imported 896,109 mt of shrimp, inclusive of all shrimp products (NOAA Fisheries, 2022). India was the largest shrimp supplier to the United States, capturing 38% of the U.S. shrimp market (Table 7).

Table 7: Top U.S. import markets for shrimp by market share in 2021. (NOAA Fisheries, 2022).

Country	Percent of Import Market
India	38%
Indonesia	19.5%
Ecuador	20.4%
Vietnam	9.7%
Thailand	4.5%
China	0.9%

According to the NOAA Fisheries trade data (2022), the majority of shrimp imports are frozen, totaling 886,543 mt versus 1,023 mt of fresh products[3]. India was the largest supplier to United States markets for frozen shrimp products, with a total of 338,926 mt, followed by Ecuador and Indonesia with 182,633 and 173,294 mt, respectively (Figure 9). For fresh shrimp products, Ecuador was the top supplier with 365 mt, while India was second with 331 in 2021 (Figure 10).

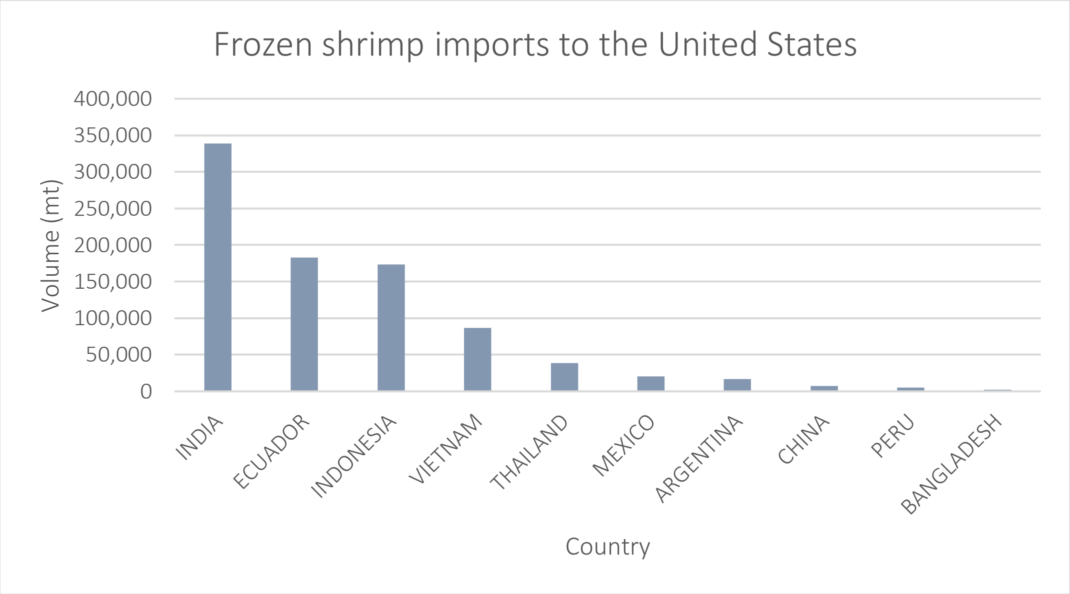


Figure 9: Frozen shrimp imports to the United States for the top 10 countries by volume (mt) in 2021. Source: (NOAA Fisheries, 2022).

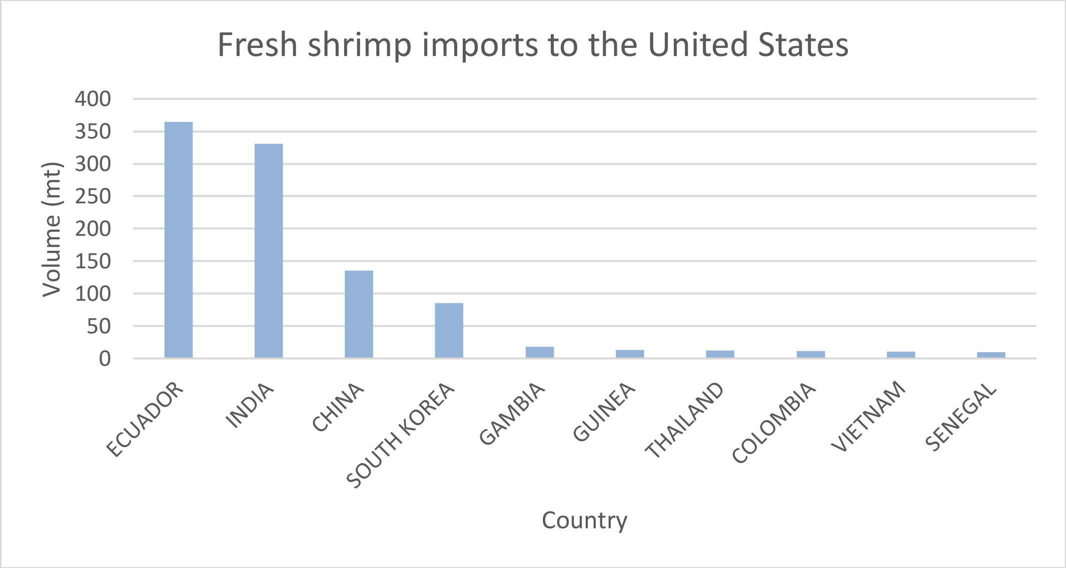


Figure 10: Fresh shrimp imports to the United States for the top 10 countries by volume (mt) in 2021. Source: (NOAA Fisheries, 2022)

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[3] Products labeled in the NMFS website that are described as Canned Shrimp, dried/salted/brine, other preparations, and prepared dinner were excluded from this analysis.

Criterion 1—Data

Overall, the availability and quality of data for shrimp farmed in U.S. semi-intensive and intensive ponds is considered moderate to high because it gives a reliable representation of operations and/or impacts. Although there are some data gaps and some of the available information is aggregated, these deficiencies are considered noncritical. Hence, the analysts can confidently determine the level of sustainability under which the industry operates. A Feed Data Request was completed by two feed manufacturers, which provided a comprehensive overview of feed use efficiency, proximate ingredient composition, marine ingredient sources, and countries of origin. Additional information from the literature and personal communications with representatives of the U.S. shrimp industry were used to confirm and contextualize the parameter ranges of the available data.

Criterion 5—Feed

Brief Summary

Overall, whiteleg shrimp feeds in the U.S. use fishmeal and fish oil made from whole wild fish and by-product sources with an eFCR of 1.4. The fishmeal inclusion level is moderate (14.4%); over one-third of it (34.9%) is sourced from fishery and/or aquaculture by-products, and the rest (65.1%) from whole-fish reduction processes. The fish oil inclusion level is low at 1.4%, and almost half (47.8%) comes from by-product sources. The resulting score for Factor 5.1a Forage Fish Efficiency Ratio (FFER) is low (0.599), meaning that from first principles, 0.599 mt of wild fish are needed to produce the fishmeal required for 1 mt of farmed shrimp. Most of the fishmeal used by U.S. feed suppliers are sourced from MSC, IFFO-RS certified, or SFW Yellow-rated (Good Alternative) fisheries and result in a score for Factor 5.1b Source fishery sustainability of 7 out of 10. The low inclusion levels of these wild fish ingredients in U.S. shrimp feeds combined with the sustainability of raw materials result in a Factor 5.1 Wild fish use score of 7.35 out of 10. Factor 5.2 Net protein gain or loss scores 3 out of 10 and is driven by a moderate-high net protein loss of –63.67%. Factor 5.3 Feed footprint scores 6 out of 10 due to a moderate feed footprint of 15.95 kg CO_2-eq. per kg of harvested protein. Altogether, Factor 5.1, 7.35 out of 10, Factor 5.2, 3 out of 10, and Factor 5.3, 6 out of 10, combine for a final score of 5.93 out of 10, which results in a Yellow rating for Criterion 5—Feed.

Justification of Ranking

The following feed analysis is inclusive of semi-intensive and intensive shrimp pond production in the United States.

In the U.S., the majority of farmed shrimp are fed commercial pelleted feeds produced by Rangen Feeds (Wilbur-Ellis Nutrition LLC), Zeigler Bros Inc., Skretting, or Cargill Inc. Information requests were made to each feed supplier and details regarding the composition of shrimp feeds were provided by two of these suppliers. Although feed inclusion rates may vary from batch to batch and often are influenced by the price and availability of ingredients, the data provided are considered to accurately represent more than 90% of shrimp feeds used in the U.S. All information provided by feed manufacturers is aggregated and included in this assessment, alongside information from the literature and additional personal communications.

The Seafood Watch Aquaculture Standard assesses three feed-related factors: wild fish use (including the sustainability of the source), net protein gain or loss, and the feed "footprint" or embedded climate change impact of ingredients in feed required to produce one kg of farmed shrimp protein.

Factor 5.1. Wild Fish Use

Factor 5.1 combines an estimate of the amount of wild fish used to produce farmed shrimp with a measure of the sustainability of the source fisheries. Table 4 shows the data used and the calculated Fish Feed Equivalency ratio (FFER) for fishmeal and fish oil.

Factor 5.1a – Feed Fish Efficiency Ratio (FFER)

The Feed Fish Efficiency Ratio (FFER) for aquaculture systems is driven by the feed conversion ratio (FCR), the amount of fish used in feeds, and the source of the marine ingredients (i.e., does the fishmeal and fish oil come from processing by-products or whole fish targeted by wild capture fisheries). For a summary of all values used to calculate the FFER, see Table 8.

FCR is the ratio of feed given to an animal per weight gained, measured in mass (e.g., an FCR of 1.4:1 means that 1.4 kg of feed is required to produce 1 kg of fish). It can be reported as either biological FCR (bFCR), which is the straightforward comparison of feed given to weight gained, or economic FCR (eFCR), which is the amount of feed given per weight harvested (i.e., accounting for mortalities, escapes, and other losses of otherwise-gained harvestable fish). The Seafood Watch Aquaculture Standard utilizes the eFCR. Using a single eFCR value to represent an entire industry is challenging. The difficulty is rooted in the differences in shrimp genetics, feed formulations, farm practices, the occurrence of disease, and more. The most representative data available on U.S. shrimp production come from recent literature, as well as personal communications with farmers and academic researchers (Amaya et al. 2006; Ghamkhar and Hicks, 2020; Naylor, 2021; Tacon et al. 2021; pers. comm., Dr. Allen Davis, Auburn University, February 2022; pers. comm., Grant Kunishima, Kona Bay Shrimp, March 2022; Michael Hooper, Bowers Shrimp, December 2021). As a result, an eFCR of 1.4 is considered representative of the U.S. shrimp industry, so it is the value used in this assessment. An eFCR value of 1.4 is also consistent with global shrimp production, which has historically seen eFCRs in the range of 1.2 to 2.0 (Tacon and Metian, 2008), and it approximates with more recent estimates that report a global average of 1.6 (Tacon, 2017, 2019, 2021).

Similarly, the ingredient composition for shrimp feed is highly variable, and the information available in the literature and obtained through feed manufacturers and stakeholders show wide ranges of inclusion levels. A single inclusion value for fishmeal and fish oil was determined by averaging the lower and upper bound of the ranges obtained from literature and stakeholders, then weighted based on market share estimated by the manufacturers (Eq. 1) (Amaya et al. 2006; Naylor, 2021; Tacon and Metian 2008; pers. comm., Dr. Allen Davis, Auburn University, February 2022; pers. comm., Grant Kunishima, Kona Bay Shrimp, March 2022; Michael Hooper, Bowers Shrimp, December 2021; anonymous feed manufacturer, April 2022).

(Eq. 1)

$$FM_{inclusion} = \left(9\%_{literature\ avg.} \times M_{share\ 1}\%\right) + (15\%_{feed\ manufacturer} \times M_{share\ 2}\%)$$

$$FO_{inclusion} = \left(2.5\%_{literature\ avg.} \times M_{share\ 1}\%\right) + (1.25\%_{feed\ manufacturer} \times M_{share\ 2}\%)$$

Where:

$literature\ avg.$ = lower and upper bound of FM and FO inclusion ranges found in the literature and reported by U.S. shrimp stakeholders.

$M_{share\ n}$ = estimated market share of U.S. shrimp industry.

The calculated fishmeal (FM) and fish oil (FO) inclusions are 14.4% and 1.4%, respectively, and are consistent with the literature. For instance, more than a decade ago, commercial feeds included 5% to 50% of FM and 1% to 8% of FO (Tacon and Metian 2008; Amaya et al. 2006). But, advances in feed formulation and new alternatives to replace FM and FO have successfully reduced these ranges to 0% to 20% and 0% to 4% inclusion, respectively (Amaya, 2006; Naylor, 2021; pers. comm., Dr Allen Davis, Auburn University, February 2022; pers. comm., Grant Kunishima, Kona Bay Shrimp, March 2022; Michael Hooper, Bowers Shrimp, December 2021; pers. comm. anonymous feed manufacturers, April 2022).

The use of by-products in shrimp feeds can result in even broader inclusion ranges than other ingredients, varying by formulation and feed manufacturer. Therefore, a weighted average, determined by market share, of the data provided by two feed manufacturers was used to determine a single inclusion level for FM and FO by-products (Eq. 2).

(Eq. 2)

$$FM_{bp\ inclusion} = \left(25\%_{f.\ manufacturer\ 1} \times M_{share\ 1}\%\right) + (36\%_{f.\ manufacturer\ 2} \times M_{share\ 2}\%)$$

$$FO_{bp\ inclusion} = \left(100\%_{f.\ manufacturer\ 1} \times M_{share\ 1}\%\right) + (42\%_{f.\ manufacturer\ 2} \times M_{share\ 1}\%)$$

Where:

$\%_{f.\ manufacturer\ n}$ = by-product inclusion level for FM and FO reported by U.S. feed manufacturers.

$M_{share\ n}$ = estimated market share of U.S. shrimp industry.

As a result, 34.9% and 47.8% of fishmeal and fish oil inclusions, respectively, come from by-products. The literature of global and North American fishmeal and fish oil by-product inclusion levels indicate that the calculated FM by-product value of 34.9% is within the global industry range of 25% to 70% for FM and FO, while below the North American average of 41% for FM (IFFO website[4], accessed April 2022; Hua et al. 2018; Seafish 2018; Jackson and Newton 2016).

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[4] https://www.iffo.com/product

For fish oil by-products, the inclusion level of 47.8% is within the global range while above the North American average (22% for FO) (Jackson and Newton 2016).

Whole fish inclusion levels were determined by calculating the difference between the by-product percentages described above and 100% (Eq. 3).

(Eq. 3)

$$FM_{wf\ inclusion} = \left(100\% - FM_{bp\ inclusion}\right)$$

$$FO_{wf\ inclusion} = \left(100\% - FO_{bp\ inclusion}\right)$$

The resulting differences are 65.1% and 52.2% for fishmeal and fish oil whole fish inclusions, respectively.

The following equation (Eq. 4) calculates the fishmeal and fish oil feed fish efficiency ratio ($FFER_{FM}$ and $FFER_{FO}$). The FFER is a measure of the dependency on wild fisheries for feed ingredients using the ratio of the amount of wild fish used in feeds to the harvested farmed fish. Each variable used in these calculations, as detailed below, is also summarized in Table 8. The whole fish inclusion levels for fishmeal and fish oil are used and can be found in Table 8 as variables a and c, respectively. Only 5% of the inclusion levels for fish oil and fishmeal from by-products are considered and are also noted in Table 8 as variables b and d. In addition , the eFCR (g) and the fish oil (f) and fishmeal yield (e) values are also identified in Table 8 and used in equation 4. Note that fishmeal and fish oil yield values were not available, so global averages provided by Tacon and Metian (2008) were utilized.

(Eq. 4)

$$FFER_{FM} = \ [(a+b) \times g]/e$$

$$FFER_{FO} = [(c+d) \times g]/f$$

The resulting FFER for fishmeal is 0.599, and the FFER for fish oil is 0.303.

Table 8: Parameters used and their calculated values to determine the use of wild fish in feeding U.S. farmed shrimp.

Eq. variable	Parameter	Data
	Fishmeal inclusion level (total)	**14.4%**
a	Fishmeal inclusion level (whole fish)	9.37%
	Fishmeal inclusion level (by-product)	5.03%
b	Assessed fishmeal inclusion level (by-product)[5]	0.252%
e	Fishmeal yield	22.5%
	Fish oil inclusion level (total)	**1.4%**

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[5] The by-product inclusion level data point utilized in this equation is the reported inclusion level multiplied by 0.05. See the Seafood Watch Aquaculture standard page 38 for more information. https://www.seafoodwatch.org/globalassets/sfw/pdf/standards/aquaculture/seafood-watch-aquaculture-standard-version-a4.pdf

c	Fish oil inclusion level (whole fish)	1.065%
	Fish oil inclusion level (by-product)	0.335%
d	Assessed fish oil inclusion level (by-product)	0.017%
f	Fish oil yield	5.00%
g	Economic Feed Conversion Ratio (eFCR)	1.4
Calculated values		
Fish meal feed fish efficiency ratio (FFERfm)		0.599
Fish oil feed fish efficiency ratio (FFERfo)		0.303
Assessed FFER		**0.599**

The Feed Criterion considers the FFER from both fishmeal and fish oil and uses the higher of the two to determine the score. As seen in Table 8, the whole fish fishmeal inclusion level drives the FFER for U.S. farmed shrimp, but it is generally low becasue 34.9% of the fishmeal used is from by-products. Therefore, the score for Factor 5.1a FFER is 0.599; based on first principles, 0.599 tons of wild fish are required to provide sufficient fishmeal to produce 1 ton of farmed shrimp.

Factor 5.1b. Source fishery sustainability

This factor evaluates the sustainability of the fisheries supplying fishmeal and fish oil for U.S. whiteleg shrimp grow-out feed. The majority (about 75%) of marine raw materials are sourced from sardine fished in the Gulf of California and Gulf menhaden fished in the Gulf of Mexico. Mackerel from Chile and squid from Chile and Peru compose the remaining 25% of FM used by U.S. feed producers (pers. comm., anonymous feed manufacturer, April 2022; pers. comm., Dr. Allen Davis, Auburn University, February 2022). In rare cases, Atlantic menhaden is also sourced, but because the species is used so infrequently, it is not included in the evaluated score (pers. comm., Dr Allen Davis, Auburn University, February 2022; pers. comm., anonymous feed manufacturer, April 2022). The final inclusion of these raw materials can vary per batch produced and will depend mainly on market dynamics, such as availability and price.

The following steps were completed to calculate a final 5.1b score:

1. Determine the sustainability score for each source fishery.
2. Determine the inclusion levels for each marine ingredient.
3. Calculate whole fish and by-product 5.1b Source Fishery Sustainability scores.
4. Determine the total sustainability scores by combining the whole fish and by-product sustainability scores for fishmeal and fish oil.
5. Calculate a final Factor 5.1b score by weighting the overall Fishmeal and Fish Oil scores by the FFER of each, considering the actual biomass of fish required to produce the ingredients.

A summary of each process and resulting calculations are provided in the descriptions below.

Step 1: Determine the sustainability score for each source fishery

A summary of the following section is provided in Table 9. The following text summarizes the rationale and justification for each species, which is informed by the certification, the FishSource scores, and/or the SFW rating of the fishery.

Table 9: Source fisheries and resulting F5.1b scores.

Common Name (*Genus species*)	Country/fishing region of origin	Gear type	Relevant certifications/ratings	F5.1b Score
Sardine (*Sardinops sagax*)	Mexico	Purse Seine	MSC	6
Gulf menhaden (*Brevoortia patronus*)	United States: Gulf of Mexico	Purse Seine	MSC & IFFO RS	8
Chilean jack mackerel (*trachurus murphyi*)	Chile	Purse Seine	MSC & IFFO RS	8
Squid (*Dosidicus gigas*) meal	Chile/Peru	Artisanal Fleet	SFW Yellow	6

All FishSource scores (e.g., Management Quality: management strategy, managers compliance, fishers compliance and Stock Health: current health and future health) for Pacific sardine (*Sardinops sagax*) fished in the Gulf of California are ≥6, including a stock health score of ≥6 (FishSource, 2021d). In addition , the fishery has been certified (with conditions) by the Marine Stewardship Council since 2011. There are currently 36 vessels using purse seine nets to catch this small pelagic, with a total annual production of over 130,000 mt for 2018 and 2019 (Ruiz-Dominguez, 2019; MSC website[6], 2022). As in every fishery in Mexico, sardines are regulated by the national Ley General de Pesca y Acuacultura Sustentables (The Fisheries Law, DOF 2007). The National Fisheries Letter includes general provisions and recommendations, and the Mexican National Standard (Norma Oficial Mexicana 003-PESC-1993) outlines the management measures. The Federal Institute of Fisheries and Aquaculture (INAPESCA) is mandated to provide scientific recommendations to the Federal Commission of Fisheries and Aquaculture (CONAPESCA) enforcement agency. Both organizations are active, identifiable, and can be reached within reason. As a result, F5.1b for Pacific sardine scores 6 out of 10 for this source fishery (Table 9).

The Gulf menhaden (*Brevoortia patronus*) is fished in the Gulf of Mexico using purse seines, and all FishSource scores are ≥6, including stock health scores >9 (FishSource, 2021c). According to the Gulf States Marine Fisheries Commission's assessment in 2020, which is an update to the 2018 benchmark for the Gulf of Mexico (SEDAR 63), the Gulf of Mexico menhaden fishery is not likely overfished, nor is overfishing occurring (Schueller, 2021). Although the Commission develops and maintains regional fishery management plans for the largest fisheries that coastal states share, these fisheries operate under the Inter-jurisdictional Fisheries Act of 1949. Therefore, the Regional Management Plan for Gulf menhaden asserts that each of the five individual states exercises the most direct management authority for this fish stock (Vanderkooy and Smith 2015). For instance, there is no Gulf-wide catch limit for Gulf menhaden, and Texas (a minor producer) adopted its own catch quota, which went into effect

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[6] https://fisheries.msc.org/en/fisheries/

in 2009 (FishSource, 2021c). Although fishery managers have raised concerns about the uncertainty regarding the estimated biomass of Gulf menhaden, they have agreed that the stock is likely not undergoing overfishing and is likely not overfished, mainly because of the following factors: the fishery's historical population structure, its accurate and available catch records, a small fleet, only a few landing ports, relatively stable productivity, the fact that almost all fish reach maturity and spawn before fishing season starts, and a relatively consistent relationship between measured effort and catch (suggesting that harvests have been well regulated) (Schueller, 2021; Vanderkooy and Smith, 2002 and 2015). As a result, F5.1b for Gulf menhaden scores 8 out of 10 for this source fishery (Table 9).

Similarly, all FishSource scores for Chilean jack mackerel (*Trachurus murphyi*) fished with purse seines are ≥6, including stock health scores of >9 (FishSource, 2021b). This fishery achieved the MSC certification and the Global Standard for Responsible Supply of Marine Ingredients (IFFO-RS) in 2019 (MSC website 2022; Daly, 2019). The South Pacific Regional Fisheries Management Organization has been conducting Chilean jack mackerel stock assessments since 2010. In 2013, catch limits were agreed upon for the assessment unit area and for the Convention area (FishSource, 2021b). The spawning stock has been fluctuating around the maximum sustainable yield but is now above this threshold and has continued to show signs of improvement since 2010 (FishSource, 2021b). As a result, F5.1b for Chilean jack mackerel scores 8 out of 10 for this source fishery (Table 9).

The jumbo squid (*Dosidicus gigas*) used for U.S. shrimp feeds comes 100% from by-products and is harvested through Chilean and Peruvian artisanal fisheries, primarily using jiggers (pers. comm., anonymous feed manufacturer, April 2022; SFW, 2018). Both Chilean and Peruvian squid receive a SFW Yellow rating and score of 3.5 (Good Alternative). The stock inside Chilean and Peruvian EEZs is not considered depleted, and fishing effort does not exceed recommended levels (SFW, 2018). A recent stock assessment on Humboldt squid outside these EEZs showed no evidence of overfishing. Refer to the complete SFW assessment for more details on these fisheries. As a result, F5.1b for jumbo squid scores 6 out of 10 for this source fishery (Table 9).

Step 2. Determine the inclusion levels for each marine ingredient.

Some estimates were made to determine the inclusion levels for each marine ingredient. Whole fish and by-products inclusion level values for each species used in FM and FO were provided by a feed manufacturer and are shown under the section *Feed manufacturer given values* in Table 10. To determine each species' contribution to fishmeal and fish oil whole fish and by-product inclusion levels, equation 5 is used (see Eq. 5). But, when summed, the resulting calculations do not equal the calculated fishmeal and fish oil inclusion levels for whole fish and by-products. So minor adjustments were made, and the resulting scores are shown in Table 10 under the *Resulting calculated inclusion levels* section.

Table 10: Feed manufacturer marine ingredient composition for U.S. shrimp feed.

Common Name (*Genus species*)	Feed manufacturer given values			Resulting calculated inclusion levels			
	Sp. Inclusion %	Whole fish %	By-product %	FM_{WF}	FM_{BP}	FO_{WF}	FO_{BP}
Sardine (*Sardinops sagax*)	54.1	75	25	5.95	1.9	0.68	0.23
Gulf menhaden (*Brevoortia patronus*)	20.8	100	0	3.05	0	0.35	0
Chilean jack mackerel (*Trachurus murphyi*)	8.3	25	75	0.37	0.83	0.035	0.105
Chilean squid* (*Dosidicus gigas*)	8.35	0	100	0	1.15	0	0
Peruvian squid* (*Dosidicus gigas*)	8.35	0	100	0	1.15	0	0
Total	99.9	–	–	9.37	5.03	1.065	0.335

* The *s*quid used in shrimp diets does not contribute to the composition of fish oil, and it is only used as in ingredient in their fishmeal.

The following calculations show how the approximated inclusion level for each species used in U.S. shrimp feeds was determined:

(Eq. 5)

$$Sp.FM_{WF}\ Inclusion\ \% = Sp_{inclusion}\% \times WF\% \times FM_{inclusion}$$

$$Sp.FM_{BP}\ Inclusion\ \% = Sp._{inclusion}\% \times BP\% \times FM_{inclusion}$$

$$Sp.FO_{WF}\ Inclusion\ \% = Sp._{inclusion}\% \times WF\% \times FO_{inclusion}$$

$$Sp.FO_{BP}\ Inclusion\ \% = Sp._{inclusion}\% \times BP\% \times FO_{inclusion}$$

Where:

For each species:

$Sp.FM_{WF}\ Inclusion\ \% = Inclusion\ rate\ of\ fish\ meal\ from\ whole\ fish$
$Sp.FM_{BP}\ Inclusion\ \% = Inclusion\ rate\ of\ fish\ meal\ from\ byproduct$
$Sp.FO_{WF}\ Inclusion\ \% = Inclusion\ rate\ of\ fish\ oil\ from\ whole\ fish$
$Sp.FO_{BP}\ Inclusion\ \% = Inclusion\ rate\ of\ fish\ oil\ from\ byproduct$

$Sp._{inclusion}\%$ = $Is\ the\ given\ percentage\ of\ each\ species\ used\ as\ raw\ materials\ in\ the\ FM\ and\ FO\ of\ U.S. shrimp's\ feed$

$FM_{inclusion} = 14.4\%\ FM\ inclusion\ rate$

$$FO_{inclusion} = 1.4\%\ FO\ inclusion\ rate$$

The resulting inclusion levels per species are included in Table 10.

Step 3. Calculate whole fish and by-product 5.1b Source Fishery Sustainability scores.

After determining each species' sustainability score and its individual inclusion levels through the procedures shown in Step 1 and 2, a single Factor 5.1b Source Fishery Sustainability score for each marine ingredient was determined and included in Table 11.

Table 11: Marine ingredients inclusion levels and sustainability scores.

Marine Ingredient	Inclusion (%)	Sustainability Score
Fishmeal from whole fish	**9.37**	
Mexican sardine (*Sardinops sagax*)	5.95	6
Gulf menhaden (*Brevoortia patronus*)	3.05	8
Chilean jack mackerel (*Trachurus murphyi*)	0.37	8
Sustainability score for fishmeal whole fish		6.73
Fishmeal from by-product	**5.03**	
Mexican sardine (*Sardinops sagax*)	1.9	6
Peruvian squid meal (*Dosidicus gigas*)	1.15	6
Chilean squid meal (*Dosidicus gigas*)	1.15	6
Chilean jack mackerel (*Trachurus murphyi*)	0.83	8
Sustainability score for fishmeal by-products		6.33
Fish oil from whole fish	**1.065**	
Mexican sardine (*Sardinops sagax*)	0.68	6
Gulf menhaden (*Brevoortia patronus*)	0.35	8
Chilean jack mackerel (*Trachurus murphyi*)	0.035	8
Sustainability score for fish oil whole fish		6.723
Fish oil from by-products	**0.335**	
Mexican sardine (*Sardinops sagax*)	0.23	6
Chilean jack mackerel (*Trachurus murphyi*)	0.105	8
Sustainability score for fish oil by-products		6.627

The equations below are used to determine a single F5.1b Source Fishery Sustainability score for fishmeal and fish oil sourced from whole fish and by-products (Eq. 6).

(Eq. 6)

$$S.Score_{FM-WF} = \Sigma(\mathrm{K}_n/\alpha_n) \times \mathrm{F}_n$$

$$S.Score_{FM-BP} = \Sigma(\mathrm{K}_n/\alpha_n) \times \mathrm{F}_n$$

$$S.Score_{FO-WF} = \Sigma(\mathrm{K}_n/\alpha_n) \times \mathrm{F}_n$$

$$S.Score_{FO-BP} = \Sigma(\mathrm{K}_n/\alpha_n) \times \mathrm{F}_n$$

Where:

K_n = Inclusion (%) of each type of marine ingredient

α_n= Total fishmeal or fish oil inclusion from whole fish or by-product for each feed type

F_n = SFW 5.1b sustainability score for each type of marine ingredient

The results of the calculations of Step 3 are included in Table 11, under each marine ingredient type (e.g., Sustainability score for fishmeal whole fish).

Step 4: Determine the total sustainability scores by combining the whole fish and by-product sustainability scores for fishmeal and fish oil.

The results of the calculations described below are summarized in Table 12.

Table 12. Ingredient inclusion levels and total sustainability scores.

Marine Ingredient	Inclusion (%)	Sustainability Score
Weighted fishmeal sustainability score (including 5% by-products)	14.4	6.710
Weighted fish oil sustainability score (including 5% by-products)	1.4	6.718
Factor 5.1b score		**6.713**

Using the fishmeal and fish oil sustainability score values for whole fish and by-products calculated in Step 3, the following equation is then used to calculate the weighted overall sustainability scores for total fishmeal and fish oil (Eq. 7):

(Eq. 7)

$$S.Score\ _{FMtotal} = (S.Score_{FM-WF} \times 0.95) + (S.Score_{FM-BP}\ \times 0.05)$$

$$S.Score_{FOtotal} = (S.Score_{FO-WF} \times 0.95) + (S.Score_{FO-BP}\ \times 0.05)$$

Where:

$S.Score_{FM-WF}$ = weighted whole fish sustainability score for fishmeal
$S.Score_{FM-BP}$ = weighted by-product sustainability score for fishmeal, considering only 5%
$S.Score_{FO-WF}$ = weighted whole fish sustainability score for fish oil
$S.Score_{FO-BP}$ = weighted by-product sustainability score for fish oil, considering only 5%

Step 5: Calculate a final Factor 5.1b score by weighting the total Fishmeal and Fish Oil scores by the FFER of each, considering the actual biomass of fish required to produce the ingredients.

The last step is to modify the weighted overall sustainability scores for fishmeal (6.710) and fish oil (6.718) by their respective FFER calculated in F5.1a ($FFER_{FM}$ = 0.599; $FFER_{FO}$ = 0.303). This is done to accurately attribute the sustainability of source fishery scores with the biomass utilized for shrimp feed, and the following equation is used (Eq. 8):

$$\text{Final 5.1b score } = \frac{(FFER_{FM} \times S.Score_{FMtotal}) + (FFER_{FO} \times S.Score_{FOtotal})}{(FFER_{FM} \times FFER_{FO})} \tag{Eq. 8}$$

As a result, the Final 5.1b Source fishery sustainability score is 6.713 out of 10. Most of the fishmeal used by U.S. feed suppliers is sourced from MSC or IFFO-RS certified fisheries and receives FishSource scores greater than 6, while the squid meal is produced 100% from by-products that originate from artisanal fisheries that are rated Yellow (Good Alternative) by SFW. Each individual marine source ingredient results in SFW sustainability scores of 6 or 8. Once each ingredient's inclusion levels are accounted for, then combined with the sustainability score, and eventually contextualized with the FFER, the resulting fishmeal and fish oil in U.S. shrimp feeds combine for a final score for Factor 5.1b SFW fishery sustainability of 6.713 (Table 12), which is rounded to 7 out of 10.

The FFER Factor 5.1a score of 0.599 is combined with Factor 5.1b Source fishery sustainability score of 7 out of 10 for a Factor 5.1—Wild Fish Use score of 7.35 out of 10.

Factor 5.2. Net Protein Gain or Loss

Factor 5.2 measures the net protein efficiency of the fish farming process based on the feed protein inputs and the harvested fish protein outputs. The net protein gain or loss is calculated according to the following equation:

$$\text{Net Protein } = \frac{[\text{Harvested fish protein content \%} - (\text{feed protein content \%} \times \text{eFCR})]}{(\text{feed protein content \%} \times \text{eFCR}) \times 100} \tag{Eq. 9}$$

Where:

- Harvested fish protein content, the percent of whole harvested fish, is 17.8%
- Feed protein content was reported at 35%
- eFCR was reported at 1.4

Table 13: The parameters used and their calculated values to determine the protein gain or loss in the production of farmed U.S. whiteleg shrimp.

Parameter	Data
Protein content of feed	35%
Economic Feed Conversion Ratio	1.40
Total protein INPUT per ton of farmed shrimp	490 kg
Protein content of whole harvested shrimp	17.8%
Total protein OUTPUT per ton of farmed shrimp	178.0 kg
Net protein loss	–63.67%
Seafood Watch Score (0–10)	**3**

The U.S. shrimp farms currently in operation use 35% total protein feeds for the majority of the shrimp production cycle (pers. comm., Dr Allen Davis, Auburn University, February 2022; Michael Hooper, Bowers Shrimp, December 2021; pers. comm., anonymous feed manufacturers, April 2022).

Considering the eFCR of 1.4 (see Factor 5.1a for details) alongside a whole-shrimp protein content of 17.8% (Boyd et al., 2007), the net protein loss is –63.67%. This results in a score of 3 out of 10 for Factor 5.2—Net protein gain or loss.

Factor 5.3. Feed Footprint

Factor 5.3—Feed Footprint is an approximation of the embedded Climate Change Impact value (CCI) (kg CO_2-eq including land-use change [LUC]) of the feed ingredients required to grow 1 kilogram of farmed seafood protein. This calculation is performed by mapping the ingredient composition of a typical feed used against the Global Feed Lifecycle Institute (GFLI) database[7] to estimate the CCI of 1 metric ton of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested seafood. Detailed calculation methodology can be found in Appendix 4 of the Seafood Watch Aquaculture Standard.

As noted previously, information requests were made to primary feed suppliers operating in the U.S. (Rangen Feeds (Wilbur-Ellis Nutrition LLC), Zeigler Bros Inc., Skretting, and Cargill Inc.). Although some of the acquired information was limited, enough detail was provided to map most ingredients and assign each a CCI value. Table 14 contains the inclusion levels for each ingredient and the economic allocation value for CCI, including land-use change as it appears in the GFLI database.

Typical ingredients in U.S. feeds include fishmeal and fish oil (see Factor 5.1), alongside soybean meal and soy lecithin, wheat flour and wheat products, dried distiller’s grains, rice products, and brewer’s yeast (pers. comm., Dr. Allen Davis, Auburn University, February 2022; pers. comm., anonymous feed manufacturer, April 2022). Although most of these plant and marine ingredients are produced domestically in the U.S., a significant portion of the marine ingredients are produced in Latin America (pers. comm., Dr. Allen Davis, Auburn University, February 2022; pers. comm., anonymous feed manufacturer, April 2022).

Because of the high level of transparency and detail, it was possible to map most of the ingredients against an applicable CCI estimate of the GFLI database. The best global or universal value was used for the few ingredients that did not have a corresponding estimate in the GFLI database. For instance, the global estimate classified as “Fishmeal from fishmeal and fish oil production, at plant/GLO Economic S” was used for the CCI of FM of Mexican sardine. Similarly, the classification “Fish oil from fishmeal and fish oil production, at plant/GLO Economic S” was used for the CCI of FO of Mexican sardine. In the case of FM and FO for Chilean and Peruvian species, the CCI estimate used was country-specific but not species-specific (Table 14). With

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[7] https://globalfeedlca.org/gfli-database/lcia-download/

regard to crop ingredients, the inclusion levels of milo, brewer’s yeast, and rice bran were added and assigned the CCI estimate classified as “Total vegetable meals, at plant/RER Economic S.” Soybean meal and soy lecithin used the CCI estimate classified as “Soybean meal, from crushing (solvent), at plant/GLO Economic S.” Lastly, land animal meals were mapped against species-specific but not country-specific CCI estimates, because they used a global value.

Table 14: Estimated embedded climate change impact of 1 mt of a typical U.S. shrimp feed.

Feed ingredients	Species or Ingredient	Climate Change Impact (incl. LUC) item	Ingredient inclusion %	kg CO_2-eq/mt feed
Fishmeal from whole fish	Mexican sardine (*Sardinops sagax*)	Fishmeal, from fishmeal and fish oil production, at plant/GLO Economic S	5.9	88.03
	Gulf menhaden (*Brevoortia patronus*)	Fishmeal, from Gulf menhaden, at plant/US Economic S	3	
	Chilean jack mackerel (*trachurus murphyi*)	Fishmeal, from fishmeal and oil production, at plant/CL Economic S	0.37	
Fishmeal from by-products	Mexican sardine (*Sardinops sagax*)	Fishmeal, from fishmeal and fish oil production, at plant/GLO Economic S	1.9	60.19
	Peruvian squid meal (*Dosidicus gigas*)	Fishmeal, from fishmeal and oil production, at plant/PE Economic S	1.2	
	Chilean jack mackerel (*trachurus murphyi*)	Fishmeal, from fishmeal and oil production, at plant/CL Economic S	1.2	
	Chilean squid meal (*Dosidicus gigas*)	Fishmeal, from fishmeal and oil production, at plant/CL Economic S	0.83	
Fish oil from whole fish	Mexican sardine (*Sardinops sagax*)	Fish oil, from fishmeal and fish oil production, at plant/GLO Economic S	0.68	6.94
	Gulf menhaden (*Brevoortia patronus*)	Fish oil, from Gulf menhaden, at plant/US Economic S	0.35	
	Chilean jack mackerel (*trachurus murphyi*)	Fish oil, from fishmeal and oil production, at plant/CL Economic S	0.035	
Fish oil from by-products	Mexican sardine (*Sardinops sagax*)	Fish oil, from fishmeal and fish oil production, at plant/GLO Economic S	0.23	2.44
	Chilean jack mackerel (*trachurus murphyi*)	Fish oil, from fishmeal and oil production, at plant/CL Economic S	0.105	
Total vegetable meals	Milo; brewer's yeast; rice bran	Total vegetable meals, at plant/RER Economic S	37	1778.94
	Soybean meal; soy lecithin	Soybean meal, from crushing (solvent), at plant/GLO Economic S	29	
	Wheat flour	Wheat flour, from dry milling, at plant/GLO Economic S	4	
	Wheat midds	Wheat middlings and feed, from dry milling, at plant/GLO Economic S	6	
Land animal meals	Porcine meat meal	Animal meal, pig, from dry rendering, at plant/RER Economic S	3.5	66.42
	Poultry by-product meal	Animal meal, poultry, from dry rendering, at plant/RER Economic S	3.5	
Sum of total			**98.8%**	**2002.96**

Based on the available information, the estimated embedded CCI of 1 mt of a typical U.S. shrimp feed is 2,002.96 kg CO_2-eq. Considering a whole harvest shrimp protein content of 17.8%, an eFCR of 1.4, and the total inclusion of all ingredients, the estimated kg CO_2-eq per kg of farmed seafood protein is 15.95 and is calculated using equation 9:

$$Est.\, kg\ CO2 - \frac{eq}{kg}\, of\ farmed\ seafood\ protein = \frac{eFCR}{whole\ harvested\ fish\ protein\ content} \times \left(\frac{Total\ CCI}{mt\ of\ Feed} \times \frac{10}{Total\ ingredient\ inclusion}\right) \tag{Eq. 9}$$

The feed footprint of U.S. farmed shrimp is considered low to moderate, and results in a score of 6 out of 10 for Factor 5.3—Feed Footprint.

Conclusions and Final Score

Overall, whiteleg shrimp feed in the U.S. use fishmeal and fish oil made from whole wild fish and by-product sources with an eFCR of 1.4. The fishmeal inclusion level is moderate (14.4%); over one-third of it (34.9%) is sourced from fishery and/or aquaculture by-products, and the rest (65.1%) from whole-fish reduction processes. The fish oil inclusion level is low at 1.4%, and almost half (47.8%) comes from by-product sources. The resulting score for Factor 5.1a Forage Fish Efficiency Ratio (FFER) is low (0.599), meaning that from first principles, 0.599 mt of wild fish are needed to produce the fishmeal required for 1 mt of farmed shrimp. Most of the fishmeal used by U.S. feed suppliers are sourced from MSC, IFFO-RS certified, or SFW Yellow-rated (Good Alternative) fisheries and result in a score for Factor 5.1b Source fishery sustainability of 7 out of 10. The low inclusion levels of these wild fish ingredients in U.S. shrimp feeds combined with the sustainability of raw materials result in a Factor 5.1 Wild fish use score of 7.35 out of 10. Factor 5.2—Net protein gain or loss scores 3 out of 10 and is driven by a moderate to high net protein loss of –63.67%. Factor 5.3—Feed footprint scores 6 out of 10 due to a moderate feed footprint of 15.95 kg CO_2-eq. per kg of harvested protein. Altogether, Factor 5.1, 7.35 out of 10, Factor 5.2, 3 out of 10, and Factor 5.3, 6 out of 10, combine for a final score of 5.93 out of 10, which results in a Yellow rating for Criterion 5—Feed.

Additional Updates

As of 2021, the State of Texas and the Texas Department of Agriculture[8] (TDA) no longer require aquaculture facilities licensing. But, the Texas Commission on Environmental Quality still oversees farm water quality and wastewater discharge. Farms still need to abide by the statutes outlined in chapter 134 of the Agriculture Code and acquire Exotic Species Permits through the Texas Parks and Wildlife Department.

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[8] https://www.texasagriculture.gov/regulatoryprograms/aquaculture.aspx

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